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DECARBONATION AND REMOVAL OF IRON AND MANGANESE FROM GROUND WATERS AT LOWELL, MASSACHUSETTS[1]

By F. A. Barbour

This paper describes the work already done in the removal of iron and manganese from one ground water supply at Lowell, Mass., and the method of decarbonating another supply, recommended to prevent poisoning by the action of carbonic acid on lead service pipes. As of some general interest, a description of the well system from which this city of more than 100,000 people obtains its water will be included; the experimental work on which the methods of treatment were based will be outlined, and the plant which has been constructed for the removal of iron and manganese, with the results of operation to date, will be described.

Previous to 1893 Lowell obtained its water, in great part, directly from the Merrimack River. Typhoid became prevalent and the serious epidemic of 1890–91 making evident the necessity of a better supply, a system of 2-inch and 6-inch wells was driven in the valley of River Meadow Brook in 1892–94. The yield was somewhat less than 5,000,000 gallons daily, or not sufficient for the requirements of the city, and another system of wells, located on the bank of the Merrimack River, was undertaken in 1895. The two systems proved adequate for the demands in point of quantity, but soon the quality of the water became a live issue.

[1] Read before the Richmond convention, May, 1917.

In 1899 the State Board of Health called attention to the effect of the high carbonic acid in the River Meadow Brook wells on lead pipe, stating that some forty cases of poisoning had developed and advising either the removal of the lead services or the abandonment of the supply. Following this condemnation, the supply has been drawn for the most part from the so-called "Boulevard System" on the bank of the Merrimack River, although at times, because of shortage, the wells in the River Meadow Brook valley have been used for short periods.

With the increasing draft from the Boulevard wells, a gradual depreciation in the quality of this supply resulted, due to increasing amounts of iron and manganese and evidenced physically by pronounced color and turbidity in the water as delivered to the consumers. From time to time additional wells were added, the original number of 169 being increased to about 450 in 1913, but despite the effect of the new wells in temporarily reducing the iron content of the water, the amount of this metal increased from 0.22 p.p.m. in 1897 to 1.39 p.p.m. in 1913.

Briefly then, the situation in 1913, when the author was asked to investigate and report on necessary improvements, was as follows: One ground water supply capable of furnishing 4,000,000 gallons daily, condemned because of its action on lead service pipes, but otherwise entirely acceptable, and another so loaded with metallic contents as to render its use diagreeable and unsatisfactory.

As will later appear, the solution recommended for the existing trouble comprehended the treatment of the two ground waters, one for the reduction of the carbonic acid and the other for the removal of the iron and manganese. No surface supply other than the Merrimack River is available within economic distance of Lowell, and a connection with the Wachusett Reservoir of the Metropolitan System, which supplies Boston and adjacent communities, would have cost approximately $2,000,000.

The possibility of filtering the Merrimack River involved considerations of some general interest. This river enjoys the distinction of having been made, by special enactment of the Massachusetts legislature in 1878, a free receptacle of sewage, with the result that the pollution is increasing yearly, and is now about four times as great as in 1890. Already at Lawrence, there is a question as to how long it will be practicable to obtain a supply from this stream by filtration without throwing too great a burden on the purifica-

tion plant, and while the good work of the Lawrence filter in reducing typhoid is well known to all engineers, it can be fairly stated that the filtered river water, because of the well-advertised pollution of the stream, has never been attractive to the consumers.

To the people of Lowell, accustomed to the use of a cool, safe supply from the ground, filtered Merrimack River water was out of the question, except as a necessity, and as the experimental work proved the possibility of removing the iron, manganese and carbonic acid at reasonable cost, treatment of the ground water was concluded to be the best method of obtaining a supply not only safe, but attractive.

EXPERIMENTAL WORK IN THE DECARBONATION OF THE RIVER MEADOW BROOK WELL WATER

It has been already stated that in 1899 the water from the River Meadow Brook wells, or the so-called "Cook wells," was condemned because of the action of the contained carbonic acid on lead service pipes. Neutralization or removal of this acid, the first by the addition of lime or soda, and the second by aeration, is the obvious remedy.

An experimental investigation was therefore planned to determine the amount of lead found in the untreated water after passing through 50 feet of $\frac{1}{2}$ inch lead pipe, and also the amount of lead found in the water after passing through similar coils of lead pipe when the carbonic acid had first been neutralized to various degrees by lime or removed by aeration. Three 50-foot coils of lead pipe were used, one for the raw water, another for the lime-treated water and the third for the aerated water. The effect of the period of contact on the amount of lead taken up was determined by taking samples after a period of four hours of standing in or passing through the pipe, and also after a period of fifteen hours.

The apparatus for the addition of lime consisted of a funnel-shaped saturator 24 inches high and 16 inches in diameter at the top. The lime was slaked in a small receptacle at the side of the saturator and introduced as milk of lime by a pipe which led to the bottom of the funnel. Water was introduced from a calibrated nozzle into a pipe which extended vertically through the center of the funnel to the bottom, the supply of water then rising slowly through the milk of lime and overflowing at the top from a circular

weir. The capacity of the saturator was such that when treating 5000 gallons per day of water with 1 grain of lime per gallon, the time of passage of the lime water through the saturator was about one hour.

The flow of lime water was maintained at as nearly a constant quantity as possible, and the amount of raw water was varied when it became necessary to change the quantity of lime added per gallon. The lime water was applied to the raw water without exposing the latter to the air, duplicating, as far as possible, the conditions under which, if this method of removing carbonic acid were adopted, the lime water would be discharged into the suction pipe of the pumps.

In starting the investigation, such portions of the raw, lime-treated and aerated water were passed through the lead pipes during the day that four hours were required between the time of entering and leaving these pipes. At a later date, as always in the case of the fifteen-hour exposure, the four-hour samples were collected from water which had been allowed to stand in the pipes for this length of time. In the interim between the periods during which the water stood in the pipes, the water was passed through at a rate of about 1 gallon in five minutes, the surplus of the treated water being wasted through a bypass. In general, the scheme was intended to represent, as nearly as possible, the actual conditions of a house service pipe.

The regular routine of the experimental station involved the determination, several times each day, of the dissolved oxygen and carbonic acid of the raw and aerated waters, and of the lime-treated water at the time of collecting the four and fifteen hour samples; determinations of the strength of the lime water at two hour intervals, and always, when closing down, for the four and fifteen-hour samples; determinations of the alkalinity, total hardness and iron once each day during August and September, and once each week thereafter; hourly observations of pressure on aerator nozzles; and hourly regulation of the rates of flow.

Table 1 shows the analysis of the raw water as collected from the pumps; Table 2 the relation between carbonic acid and lead content of the untreated and the lime-treated water after remaining in the pipe four hours, and Table 3 the relation between carbonic acid and lead content of untreated and lime-treated water after remaining in the pipe fifteen hours.

TABLE 1

Analyses of raw water as collected from pumps at Cook Well station

DATE	PARTS PER MILLION					PER CENT SATURATION. DISSOLVED OXYGEN
	Alkalinity	Total hardness	Incrustants	Iron	Carbonic acid	
September 1–6	31.5	57.4	25.9	0.100	39.8	12.4
September 8–13	32.0	53.8	21.2	0.075	39.8	12.6
September 15–20	31.8	55.5	23.7	0.050	43.8	11.7
September 22–27	33.0	57.1	24.1	0.100	46.4	12.3
September 29–October 4	34.0	55.0	21.0	0.035	46.2	10.6
October 5–11	34.0	56.3	22.3	0.100	46.7	8.9
October 12–18	35.0	51.3	16.3	0.050	45.6	8.1
October 19–25					46.5	10.8
October 26–November 1	32.5	56.3	23.7	0.050	47.0	12.2
Average	33.1	55.2	22.1	0.070	44.9	10.9

TABLE 2

Relation between carbonic acid and lead content of untreated and lime treated water after remaining in pipe four hours

DATE	UNTREATED WATER		LIME TREATED WATER			
	Carbonic acid	Lead	Lime added		Carbonic acid	Lead
	p.p.m.	*p.p.m.*	*p.p.m.*	*gr./gal.*	*p.p.m.*	*p.p.m.*
September 2–4	37.5	5.000	16.9	0.99	16.0	2.000
September 9–11	40.5	5.200	18.5	1.08	19.0	1.400
September 17–19	38.0	5.200	16.7	0.98	16.0	2.200
September 23–24	35.5	3.000	16.8	0.98	14.5	1.314
September 27		2.800	17.2	1.00		0.914
October 2–3	31.5	4.000	17.4	1.02	9.0	1.828
October 7	37.5	3.600	17.7	1.04	13.0	1.600
October 10	45.0	5.200	38.0	2.22	1.8	1.400
October 17–19	41.5	6.400	35.6	2.08	0.0	0.400
October 22–23	38.0	4.800	25.8	1.51	6.0	0.714
October 27–28	42.3	5.200	26.1	1.53	0.0	0.257
November 5	39.0	7.000	29.7	1.74	0.0	0.257
November 6–8	41.5	8.000	29.1	1.71	1.8	0.943
November 12	36.0	4.600	29.5	1.73	0.0	0.400
November 13	37.5	5.200	25.5	1.49	0.0	0.800

p.p.m.; parts per million.

It may first be noted that 0.5 part of lead per million has generally been considered to be the permissible maximum in a potable supply. Referring to Table 2, showing the effect of a four-hour period in the pipe, it will be seen that the lead in the untreated water averaged about 5.0 parts per million, or practically ten times the safe limit, and for a fifteen-hour period Table 3 shows 6.7 parts per million, or thirteen times the safe limit. Very obviously the untreated water is entirely unfit for use.

Again referring to these tables, it appears that by the addition of approximately one grain of lime per gallon (100 per cent available) the lead taken up by the water after a period of four hours in the pipe is reduced to 1.5 parts per million, and after a period of fifteen hours to 3.1 parts per million, or respectively three and six times the safe limit. With the increase of lime to $1\frac{3}{4}$ grains per gallon, the carbonic acid was practically neutralized, and the experiments indicated that the corrosive action on the lead was so far reduced that the lead content of the treated water, after remaining in the pipe four or fifteen hours, was approximately 0.5 part per million.

TABLE 3

Relation between carbonic acid and lead content of untreated and lime treated water after remaining in pipe fifteen hours

DATE	UNTREATED WATER		LIME TREATED WATER			
	Carbonic acid	Lead	Lime added		Carbonic acid	Lead
	p.p.m.	*p.p.m.*	*p.p.m.*	*gr./gal.*	*p.p.m.*	*p.p.m.*
August 22	34.5	15.152	17.4	1.02	16.5	6.000
August 27–28	37.2	6.000	18.1	1.06	13.0	2.752
September 2–4	34.8	4.516	17.6	1.03	6.5	5.000
September 9–11	40.6	5.200	18.9	1.11	9.0	1.800
September 17–19	38.0	3.200	16.7	0.98	14.0	1.600
October 2–3	37.0	5.600	17.6	1.03	18.0	1.915
October 7	35.5	6.000	16.0	0.94	11.0	2.600
October 10	36.0	4.344	36.0	2.11	0.0	0.400
October 17–19	39.5	10.000	32.8	1.92	0.0	0.571
October 22–23	34.5	8.000	26.5	1.55	7.2	0.800
October 27–28	34.5	7.200	24.8	1.45	2.6	0.543
November 5	37.5	8.000	30.9	1.80	0.0	0.543
November 6–8	41.0	9.000	29.1	1.70	1.0	0.543
November 12	34.5	5.200	29.9	1.75	0.0	0.257
November 13	35.0	5.600	25.3	1.48	0.0	0.400

p.p.m.; parts per million.

It was concluded from the experiments that 1.5 grains of lime per gallon would sufficiently nullify the effect of the water on lead pipe to make the supply safe, and that a lesser amount would not meet this condition. The cost of such treatment would be small, approximately $2 per million gallons, with reasonable allowance for depreciation on apparatus and for a proportionate charge for attendance by the pumping station force, but this would be a minor factor in the consideration of the expenses to the city incident to this method of decarbonation. The use of 1.5 grains per gallon to reduce the carbonic acid from 45 p.p.m. to 5 p.p.m. and the consequent increase of 45.5 p.p.m. of hardness would entail an additional cost for soap of $455 per million gallons completely softened, and, if it is assumed that in Lowell 1 gallon of the 50 gallons consumed per capita daily would be completely softened, it follows that the removal of forty parts of carbonic acid by lime would result in an increased expenditure for soap of $9.10 per million gallons of water hardened. It was therefore concluded, because of the resulting increase of the total hardness of the water to approximately one hundred parts per million—an amount too great to be satisfactory to consumers accumstomed to soft water—and because of the expense incident to such increase in hardness, that decarbonation by lime was not adapted to the Lowell conditions.

It had been hoped in starting the experiments that the addition of a fraction of a grain of lime per gallon would so far reduce the corrosive effect as to make the supply safe, but the tests indicated that such was not the case. It is of interest to note that the continued passage of water through the lead pipes did not appear to reduce the corrosive effect by the formation of any coating in the pipes.

For the aeration experiments, nozzles with ¼-inch orifice, of the type in which a central driving jet collides with four annular, revolving jets just inside the orifice, and a fine conical spray results, were used. It is believed that for a given loss of head this type of nozzle obtains the maximum possible aerating effect.

The aeration experiments showed that with a pressure of 5 pounds on the nozzle the carbonic acid could be reduced from 45 p.p.m. in the raw water to 3.3 p.p.m., and that with this reduction the effect of the water on lead pipes would be so far lessened as to render the supply safe. In stating this conclusion the fact that in the fifteen-hour tests the lead taken up somewhat exceeded 0.5

TABLE 4

Relation between carbonic acid and lead content in aerated water after remaining in pipe for four and fifteen-hour periods at Cook Wells

DATE	FOUR-HOUR SAMPLE		FIFTEEN-HOUR SAMPLE	
	Carbonic acid	Lead	Carbonic acid	Lead
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
September 9–11	3.0	0.114	3.5	0.571
September 17–19	3.5	0.457	3.0	0.543
September 23–24	4.5	0.657	3.5	0.800
October 2–3	3.5	0.457	3.0	0.657
October 7	3.5	0.400	4.5	1.143
October 17–19	4.0	0.400	3.5	0.400
October 22–23	10.0	0.400	13.0	0.743
October 27–28	17.0	0.600	16.0	0.886
October 28	3.0	0.343		
November 6–8	10.0	0.334	9.5	0.943
November 12	22.0	0.943	17.5	1.143
November 13	3.0	0.257		

p.p.m.; parts per million.

p.p.m. is not overlooked, because it is believed that the retention of the water for fifteen hours in the pipe is too severe a test, and the four-hour period of contact more nearly represents the conditions of actual use.

Figure 1 shows the relation between the pressure on the nozzle and the dissolved oxygen and carbonic acid in the aerated water. During the aeration experiments the raw water content averaged 44.9 parts per million of carbonic acid, and from the diagram it appears that with a pressure on the nozzle of 2 pounds, 85 per cent of the carbonic acid was removed; with 4 pounds, 91 per cent; with 6 pounds, 94 per cent, and with 8 pounds 94.8 per cent. To obtain as fine a spray with larger nozzles, additional pressure is required, and from observations of the reduction in carbonic acid effected by $1\frac{1}{4}$-inch nozzles of the aerator in the purification plant at Akron, Ohio, when discharging 100 gallons per minute under 7 pounds pressure, it is estimated that for the same efficiency a 50 to 75 per cent increase in the pressures shown in Figure 1 would be necessary for the size of nozzles used in practical work.

It is of interest to note that for some unexplained reason, the tests indicated that aeration is more effective than lime treatment

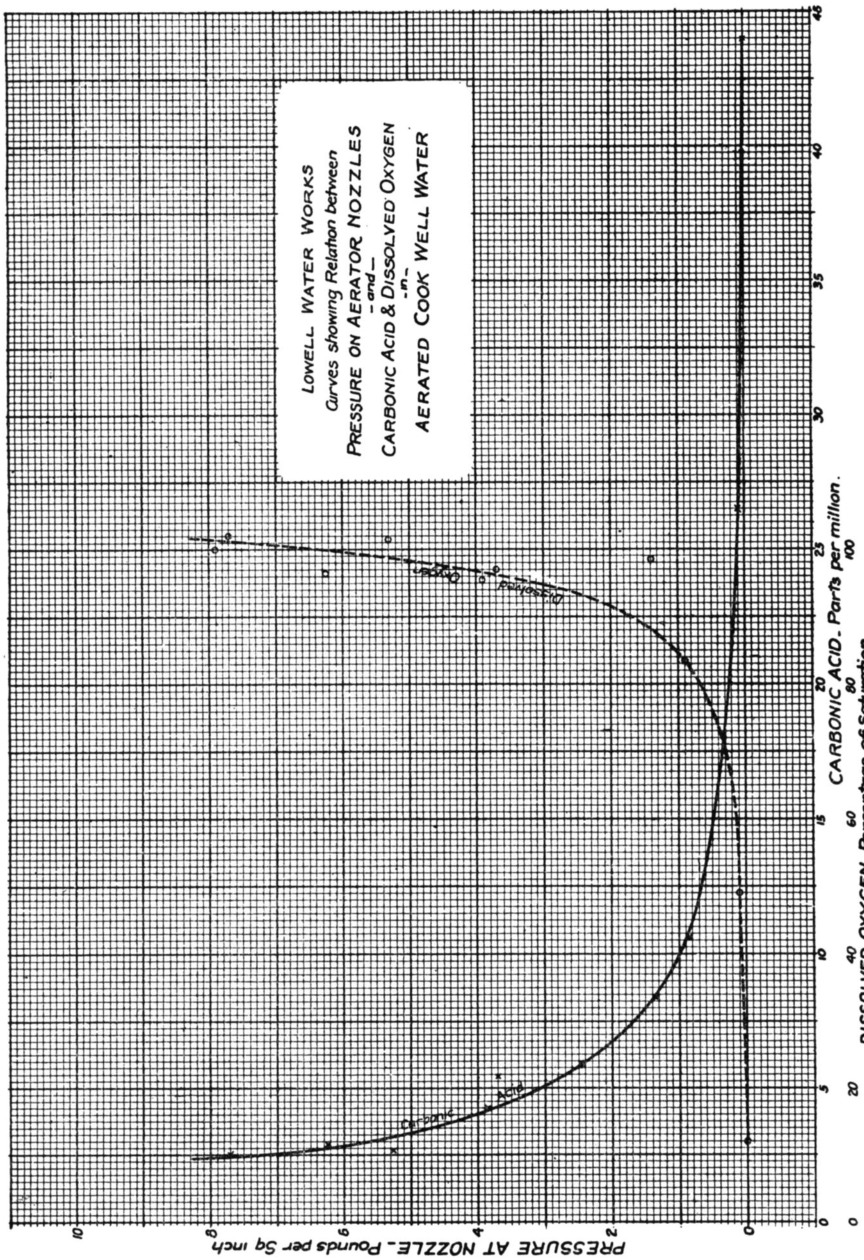

LOWELL WATER WORKS
Curves showing Relation between
PRESSURE ON AERATOR NOZZLES
-and-
CARBONIC ACID & DISSOLVED OXYGEN
-in-
AERATED COOK WELL WATER
Carbonic Acid
CARBONIC ACID. Parts per million.
DISSOLVED OXYGEN. Percentage of Saturation
PRESSURE AT NOZZLE - Pounds per Sq inch

FIG. 1.

in reducing the corrosive action, when an equal amount of carbonic acid is left in the treated water. This result is not what might be expected, because by aeration the dissolved oxygen, which has generally been considered a contributary factor in corrosion, is increased.

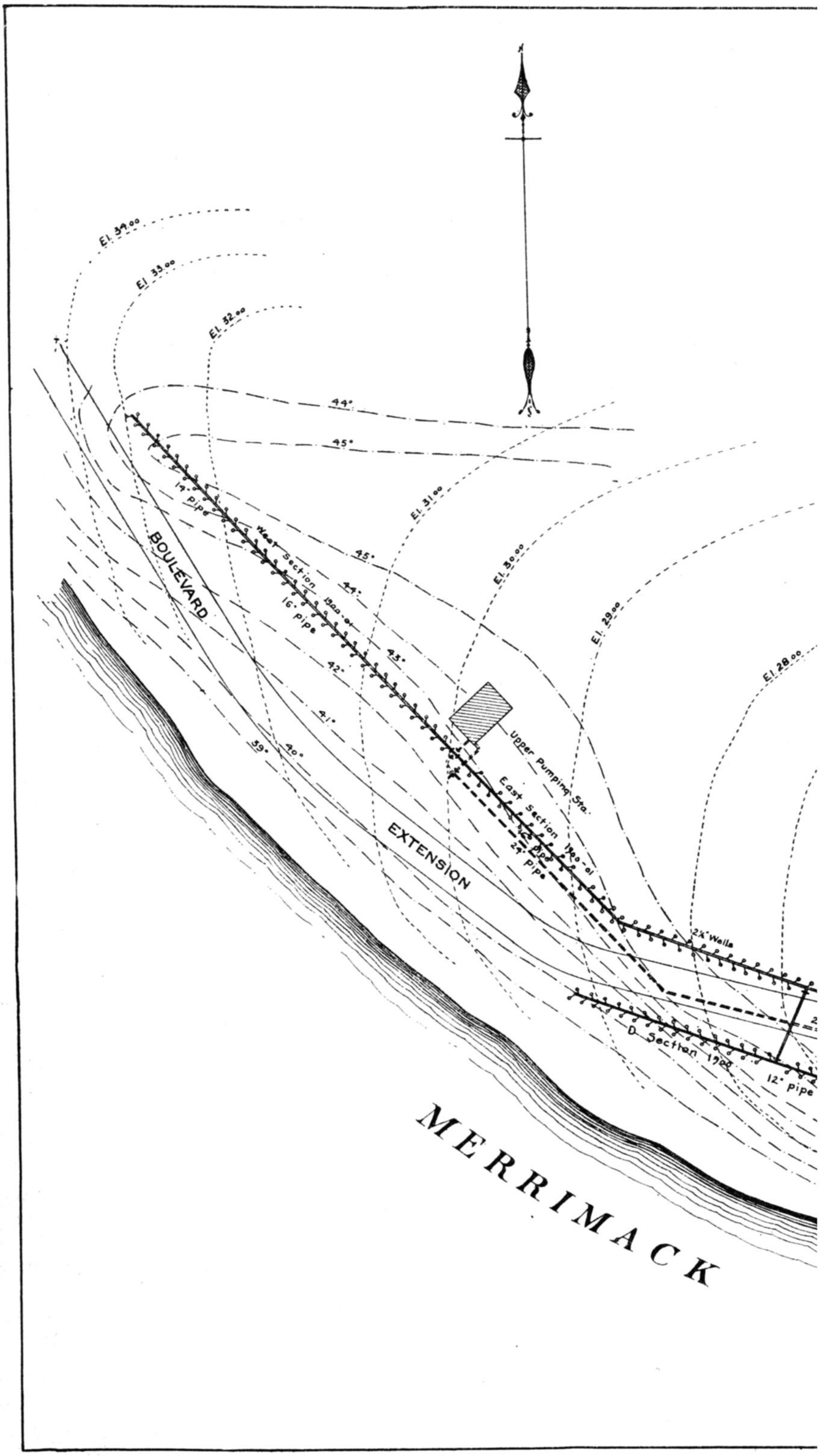
Assuming an additional lift of 30 feet for aeration, the cost of removing the carbonic acid in this way at Lowell, including fuel, interest and depreciation on aerator, collecting well and auxiliary pump, proved to be less than $3 per million gallons. This method of decarbonation was accordingly recommended, and although the plant has not yet been constructed, it will undoubtedly be provided in the near future.

THE BOULEVARD WELL SYSTEM

Before describing the plant constructed for the removal of iron and manganese from the so-called "Boulevard Supply," a brief reference to the system of wells from which some 6,000,000 gallons of water are daily obtained may be of interest.

The well field is a flat terrace on the north bank of the Merrimack River, two miles above the Pawtucket dam, by which the water is held at an elevation of about eight feet below the ground surface. The pooling effect of this dam and the location of the well field on the inside of a bend in the river provide conditions favorable for the deposition of silt and mud. Beneath the surface loam and subsoil, 10 to 20 feet of fine, micaceous, glacial flour is found, and below this, sands of varying size of particle, but all so fine as to make the use of well strainers necessary.

The well system has been gradually extended since the first 169 wells were driven in 1896. In 1900–01, 177 wells and in 1911–12, 118 wells were added, the total number now in use being about 475. Plate I shows the layout of the several lines of wells and also the temperatures and elevations of the ground water from April 6 to 11, 1914. Except for the wells driven in 1911–12, which are located about 700 feet from the river, the distance between the wells and the stream ranges from 150 to 300 feet. A considerable number of wells, driven in 1896 at a less distance from the river, were pulled up and abandoned because of the high iron contents of the water. The theory sometimes advanced that, where metals are dissolved from the underlying soils, the nearer to the stream the wells are located the less the amount of metals dissolved by the water, is not borne out by experience at Lowell.



N
S
El. 34.00
El. 33.00
El. 32.00
El. 31.00
El. 30.00
El. 29.00
El. 28.00
44°
45°
43°
42°
41°
40°
39°
14" pipe
West Section 1900-01
16" pipe
BOULEVARD
Upper Pumping Sta.
East Section 1900-01
24" pipe
EXTENSION
2½" Wells
D Section 1900
12" pipe
MERRIMACK

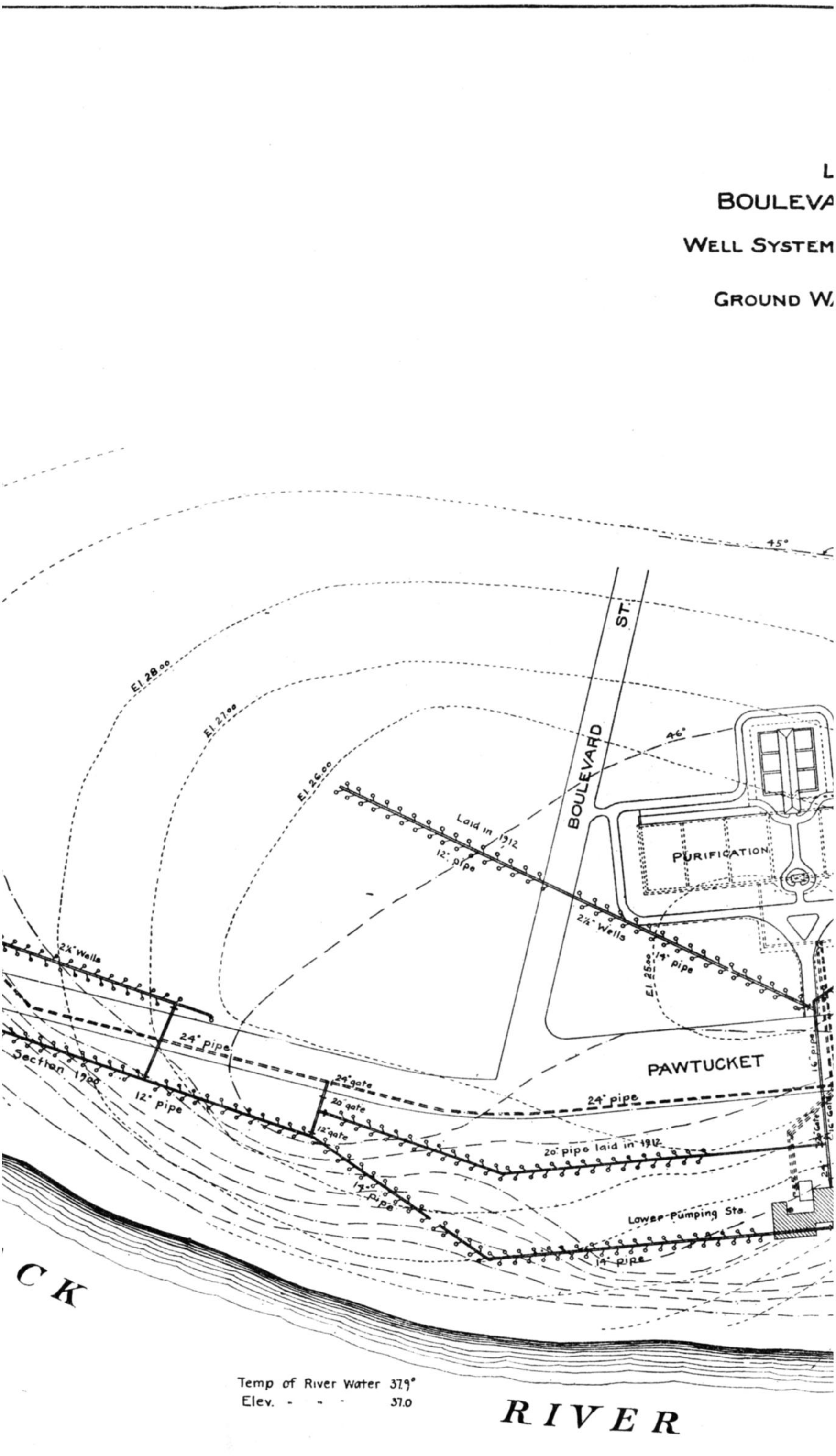

L
BOULEVA
WELL SYSTEM
GROUND W
45°
46°
BOULEVARD
ST.
El 28.00
El 27.00
El 26.00
El 25.00
Laid in 1912
12" pipe
PURIFICATION
2½" Wells
14" pipe
24" pipe
Section 1908
12" pipe
24" gate
20" gate
12" gate
PAWTUCKET
24" pipe
20" pipe laid in 1912
12" pipe
Lower Pumping Sta.
14" pipe
CK
Temp of River Water 37.9°
Elev. - - - 37.0
RIVER

PLATE I

LOWELL WATER WORKS

BOULEVARD PURIFICATION PLANT

Plan showing

WELL SYSTEM AND LAYOUT OF TREATMENT PLANT

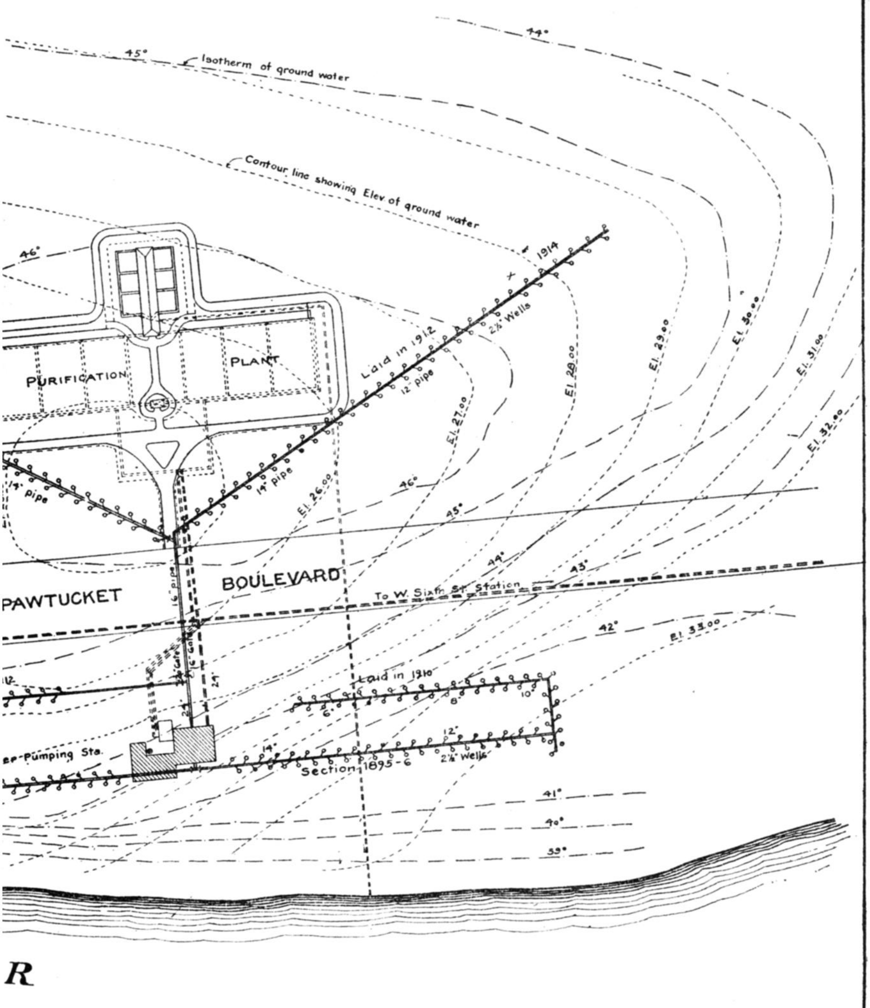
Also

GROUND WATER LEVELS AND TEMPERATURE

APRIL 6-11, 1914

0 100 200 300
Scale of Feet.

F. A. Barbour
Engineer



The wells range in depth from 35 to 40 feet, with the points on the average about 25 feet below river level. Extra heavy 2½-inch wrought iron pipe is used, with a bottom section 38 inches long, perforated by 180 ½-inch holes, and with a brass wire soldered into a groove cut spirally, with a ½-inch pitch, to maintain a space of ⅛-inch between the pipe and the surrounding strainer, which is of sheet brass perforated by longitudinal slots, of which there are 20 per inch horizontally and 6 per inch vertically. The corrosion and incrustation of the iron bottom section, particularly in the ½-inch inlet holes, has made apparent the advisability of using brass pipe in this strainer section.

A cast-iron well point 4½ inches in diameter serves to protect the strainer during driving, which is done by heavy drop hammer and without washing. Each well pipe extends to the surface of the ground, where it is capped, a tee being inserted at the level of the suction main, to which it is connected by 2½-inch iron pipe, with a flanged valve in the branch to enable each well to be isolated. The mains are flanged cast-iron pipes laid below the frost line, with grades rising to the air chamber at the pumping station.

Figure 2 shows the color, ammonias and iron in the well water from 1896 to 1916 and also the rate of draft from the wells for the same period. The gradual increase in the iron contents of the water is of interest. Starting with 0.098 p.p.m. in 1896 when the first wells were driven, the iron increased to 0.591 p.p.m. in 1900, falling back to 0.260 in 1901, as a result of 177 new wells driven in 1900–01, and from this point rising to 2.379 p.p.m. in 1911, when it was again reduced to 0.896 in 1912 by the 118 wells provided in this latter year. In the first month after driving the new wells in 1912, the iron in the water pumped from the well field averaged 0.020 p.p.m. and four months later 0.350 p.p.m., these amounts indicating clearly that practically all the water was drawn from the new wells. From an average of 0.816 p.p.m. in 1912 the iron has gradually increased to 2.28 p.p.m. in 1916.

Until the undertaking in August, 1913, of the experimental work in the removal of the iron, no determinations of manganese in the water had been made. It was then found that the amount of this metal exceeded that of the iron, and averaged 2.6 p.p.m. during the experiments. The presence of about 4.5 p.p.m. of iron and manganese, equal to about 200 pounds of metal in the water daily pumped to the city, or 35 tons per year, had naturally led to ex-

tremely unsatisfactory conditions. In solution, when drawn from the ground, these metals, by the oxidation incident to pumping, were, in great part, deposited in the pipe system, the iron nearer the source of supply, and the manganese at more distant points, forming, with the attendant Crenothrix and other fungi, a heavy

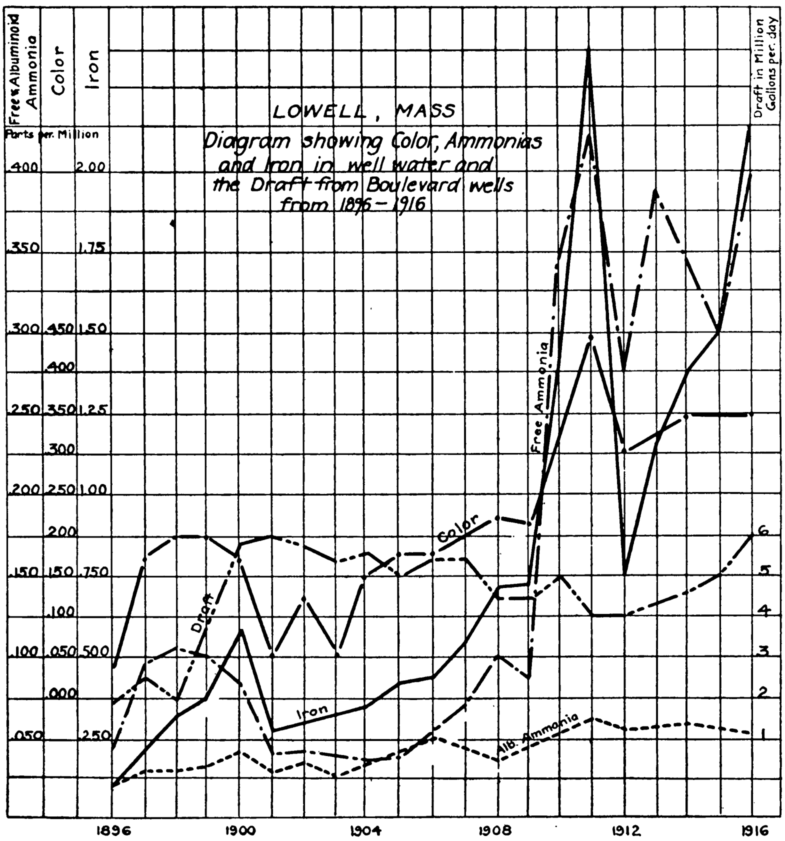


FIG. 2 COLOR, AMMONIAS, IRON AND DRAFT

slime which, when stirred up by unusual drafts, made the water entirely unfit for use.

Iron is present in greater or less amount in practically all sands, and manganese in many sands, from which ground waters are obtained. These metals in fully oxidized condition are practically insoluble, but when reduced by the organic matter in water devoid

of oxygen and containing carbonic acid are readily dissolved. Such a condition is frequently evidenced in the operation of sewage filters, when overloading of the sand and the consequent exhaustion of the dissolved oxygen quickly results in the appearance of iron and Crenothrix in the effluent, only to disappear as soon as the reducing action of the organic matter in the sewage is removed by a reduction in the rate of filtration, or by a period of rest. The determining factor in the amount of metal present in ground water is, therefore, the organic matter in the soil or brought in by the water; and while it may be possible by preliminary soil examination to guard against the location of wells in an area abnormally charged with iron and manganese, the more generally important condition is to limit the rate of draft to that at which the air in the water and soil can oxidize the organic matter present without reducing the metallic oxides to soluble form.

The Boulevard supply is dependent in great measure on infiltration from the river. The amount entering the well field at any point depends, other conditions being equal, on the difference in elevation between the water in the river and the water table at such point. The character of the water which is thus drawn from the river, its deoxidation by accumulated organic matter and its consequent tendency to throw into solution the iron and manganese deposited in the soils, is largely determined by the rate at which the water passes through the soil intervening between the river and the wells. The wells vary in age and in condition of the strainers, which gradually become clogged with silt and metallic deposits. Thus it follows that with no attempt to regulate the vacuum maintained at the station to the condition of the different well lines, the newest wells, or those last cleaned, have furnished the greater part of the water, and observations of the water table have shown that only in the area adjacent to the cleaner wells is the ground water much depressed, a condition illustrated by the lines showing elevation of the ground water in Plate I. The result has been a high rate of infiltration from the river through a limited area, the overloading of the sub-surface sands and the development of the conditions best calculated to throw into solution the iron and manganese in the soils.

By throttling all suction lines connected to the newer or cleaner wells, so as to equalize the supply drawn from the different parts of the field, the rapid clogging of the strainers, due to excessive

drafts, can be materially reduced, and the resulting rate of infiltration through a larger section will at least retard the increase in metallic contents of the water. Also, by extending the well system so as to limit the draft to the rate which can be maintained without too rapid clogging of the stariners or overworking of the adjacent wells, the amount of iron and manganese thrown into solution can be lessened.

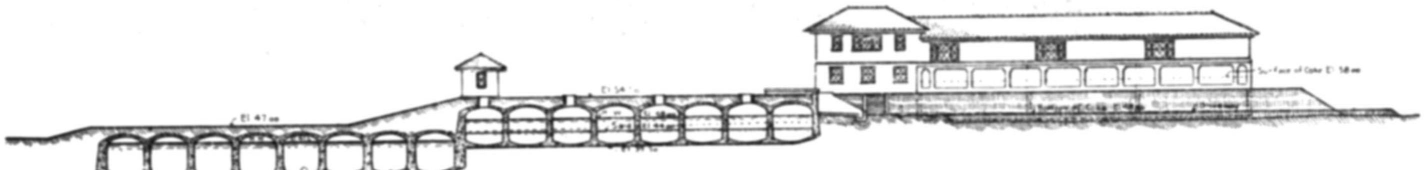
It was accordingly recommended in connection with the development of the purification plant, that the well system be extended both up and down stream, that pitometer gaugings of the different suction lines and observations of the elevations of the water table in indicator wells should be made the basis of a system of control by which a more uniform working of the well field might be effected; and that all wells should in future be sunk by wash pipe and the strainer section be made of brass instead of cast iron.

EXPERIMENTAL WORK IN THE REMOVAL OF IRON AND MANGANESE

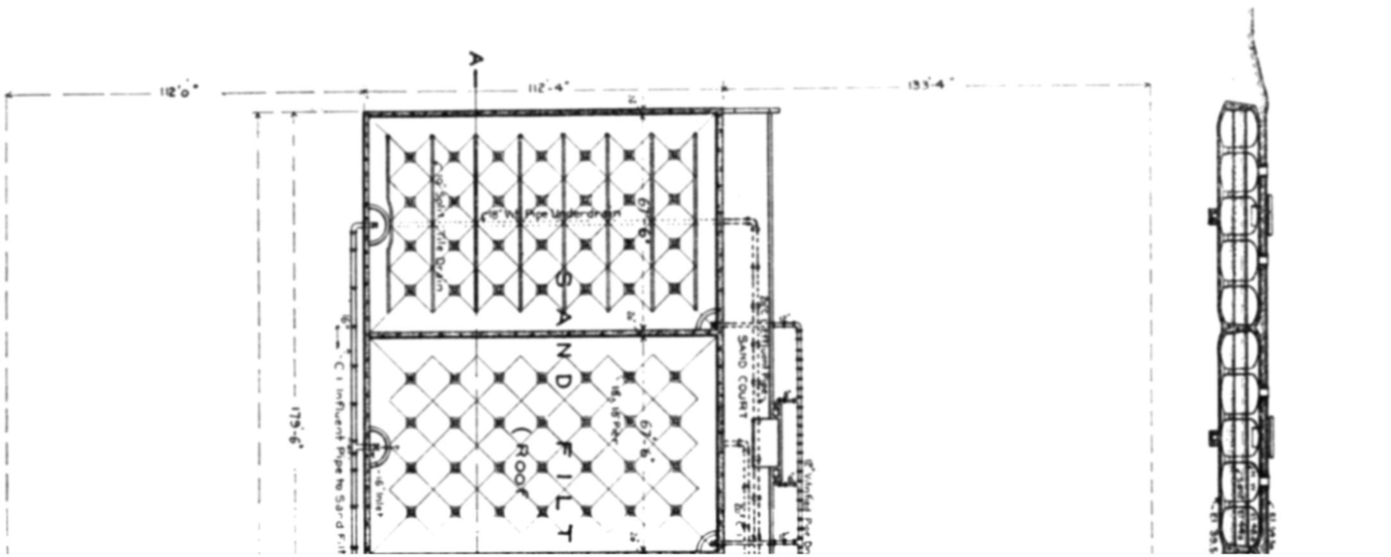
To provide information for the design of works to remove the iron and manganese from the Boulevard supply, an experimental plant was put in service in August, 1913, and operated for several months under the direction of Clifton L. Rice. This investigation included studies of various combinations of aeration, sedimentation, prefilters of gravel and coke of different depths, and final sand filtration. The regular analytical work consisted of daily determinations of the carbonic acid, dissolved oxygen, iron and manganese in raw water, after aeration, prefilter effluent and sand filter effluent. The prefilter was operated at rates varying from 25,000,000 to 70,000,000 gallons per acre per day, and the sand filter at rates varying from 6,000,000 to 10,000,000 gallons per acre per day.

Different waters require different treatments for the economic removal of metals in solution. When not accompanied by interfering agents, iron can be readily removed by aeration and sand filtration. In the presence of organic matter or manganese, the iron may be held in colloidal form and cannot be so readily precipitated and filtered out. In some waters excessive aeration is possible, and the retention of a certain portion of the carbonic acid is apparently necessary to prevent the organic matter from interfering with the precipitation of the iron.

The experiments therefore comprehended a progressive study,



Sectional Elevation on Line C-D



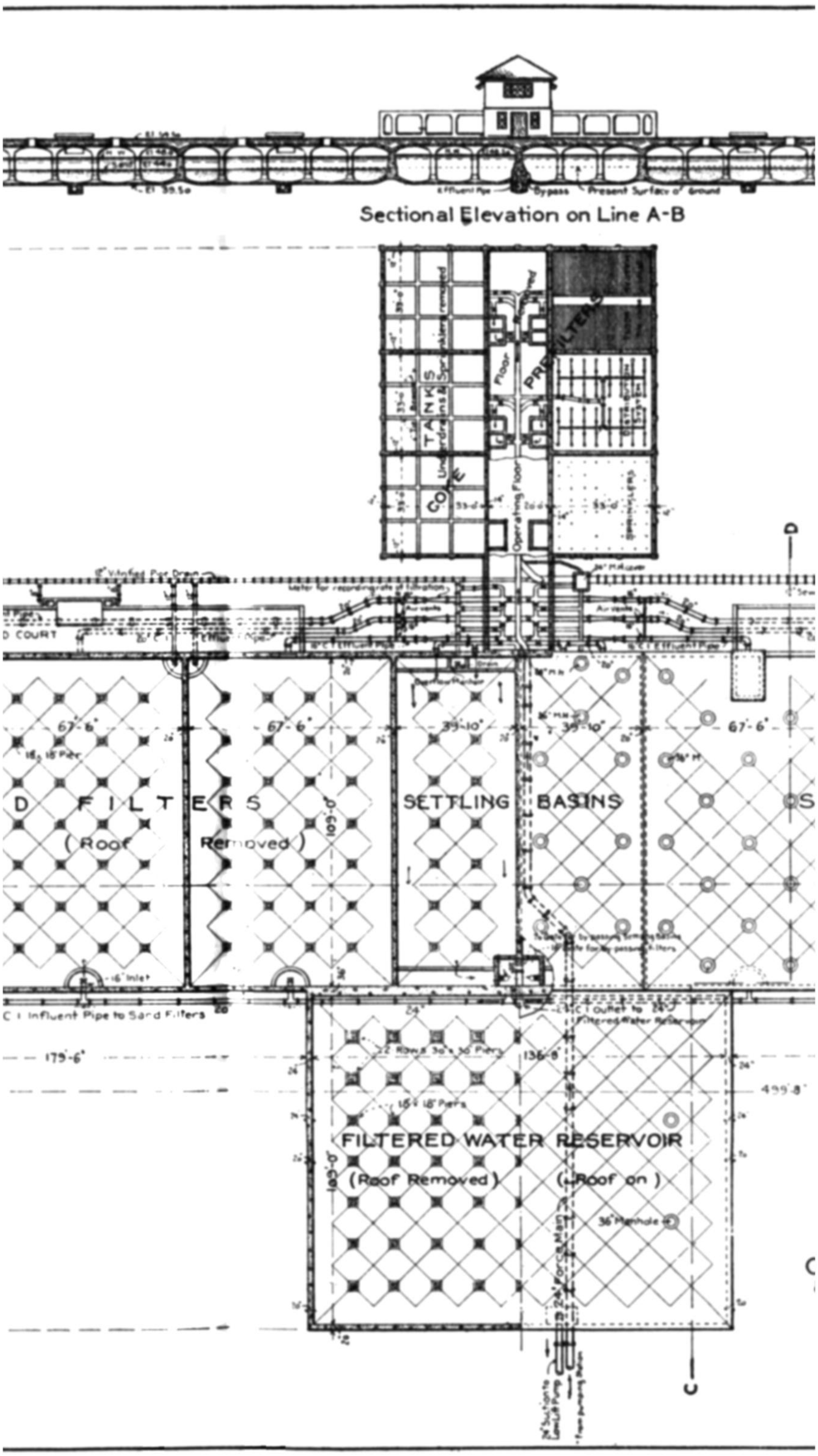
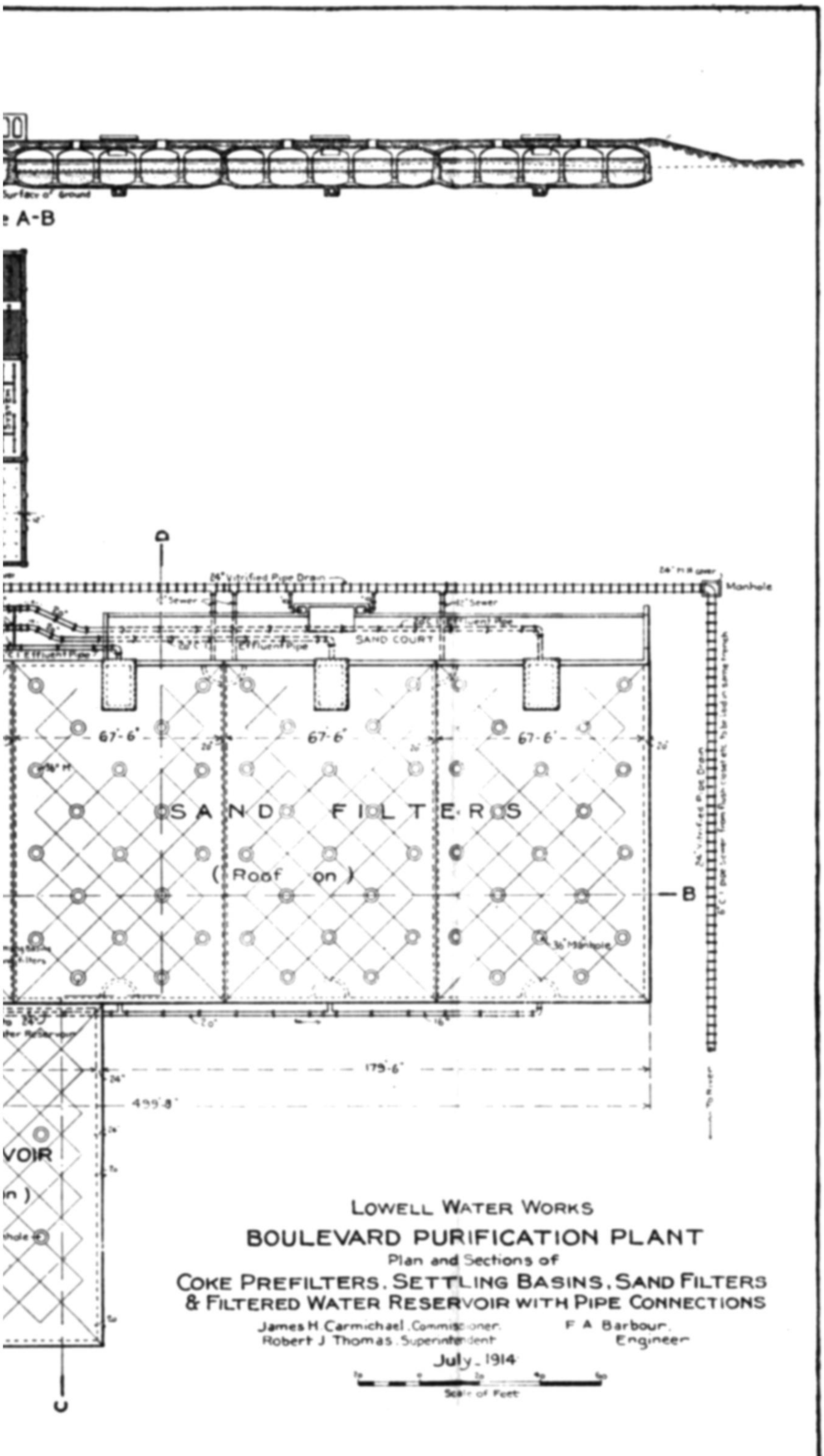

Sectional Elevation on Line A-B
COKE TANKS
PREFILTERS
Operating Floor
D FILTERS
(Roof Removed)
SETTLING BASINS
FILTERED WATER RESERVOIR
(Roof Removed)
(Roof on)
C.I. Influent Pipe to Sand Filters
179'-6"
67'-6"
39'-10"
136'-8"
499'-8"
109'-0"
36" Manhole

Plate II


A-B
D
SAND FILTERS
(Roof on)
SAND COURT
Effluent Pipe
Manhole
36" Manhole
67'-6"
67'-6"
67'-6"
179'-6"
499'-8"
B
C
LOWELL WATER WORKS
BOULEVARD PURIFICATION PLANT
Plan and Sections of
COKE PREFILTERS, SETTLING BASINS, SAND FILTERS
& FILTERED WATER RESERVOIR WITH PIPE CONNECTIONS
James H. Carmichael, Commissioner
Robert J. Thomas, Superintendent
F. A. Barbour, Engineer
July, 1914
Scale of Feet

starting with simple aeration and leading to more highly developed preliminary treatment by filters of coarse material operated as tricklers or contact beds. It will be sufficient here to state that it was found that the iron and manganese could not be removed by aeration and direct application to sand filters, nor by aeration, sedimentation and sand filters. It was found that excessive aeration was possible, that for the successful removal of the iron and manganese it was apparently necessary to retain 10 p.p.m. of carbonic acid in the prefilter effluent and that the best results were obtained by operating the prefilter as a contact bed rather than as a trickler.

In the final test run with the prefilter, of coke 8 feet deep, operating at a rate of 67,500,000 gallons per acre daily, and the sand filter (30 inches deep, 0.34 mm. effective size, uniformity coefficient 2.56) at a rate of 10,000,000 gallons per acre daily, the iron was reduced from 1.05 p.p.m. to 0.09 p.p.m. per million, the prefilter removing 40 to 60 per cent of the manganese and 55 to 80 per cent of the iron. In this run, with one raking, water equivalent to 590,000,000 gallons per acre passed through the sand filter before it became necessary to scrape.

THE PLANT FOR THE REMOVAL OF IRON AND MANGANESE

Based on the experimental results, a plant with a gross capacity of 10,000,000 gallons daily was designed and constructed, comprising six coke prefilters, 10 feet deep and 0.15 acre in total area, two settling tanks of a total capacity of 500,000 gallons, providing approximately one hour sedimentation, six sand filters with a total area of 1 acre and a filtered water reservoir of 1,000,000 gallons capacity. Plate II shows the general plan and sections.

The plant is located in the well field about 600 feet north of the pumping station. The water is drafted from the wells by one or other of the two 8,000,000-gallon triple, vertical, Holly plunger pumps, and lifted to the treatment plant through a 24-inch force main which extends to and through the prefilter pipe gallery, with branches to each prefilter. The pumps run twenty-four hours daily, at as nearly a regular rate as consumption in the city will permit, and the rate of operating the treatment plant is determined by the discharge of these pumps.

The water is aerated and distributed over the surface of each prefilter by 64 spray nozzles, Figure 3, set 4 feet $1\frac{1}{2}$ inches on cen-

ters and 6 inches above the surface of the coke. The nozzles are formed of brass caps, $\frac{1}{8}$ inch thick, screwed on the top of 2-inch riser pipes, 6 inches long, and perforated by twenty-one $\frac{5}{32}$-inch holes. The cap is domed with a radius of 3 inches and the holes are placed in three circles, 0.21 inch, 0.58 inch and 1.0 inch distant from the axis. It was found by experiment that the coefficient of discharge of the $\frac{5}{32}$-inch holes ranged from 0.80 to 0.85 and that with the holes placed as above described, the sprays, under a head of 2.5 feet at the nozzles, would fall at distances of 7, 16 and 24 inches from the

FIG. 3. PREFILTER AERATING SPRAY NOZZLES

nozzles, rising to heights of about eight-tenths of the head, and increasing the dissolved oxygen content from 12 to 50 per cent of saturation, when discharging at a rate equivalent to 1,250,000 gallons daily on each prefilter, which was the rate adopted for the design of the nozzles.

The prefilters are square reinforced concrete boxes, 33 feet by 33 feet inside horizontal dimensions, set in two parallel rows of three with a space of 20 feet between to provide a pipe gallery (Figs. 4 and 5). The inner walls support the operating gallery substructure, which contains the valve stands and indicating apparatus used in

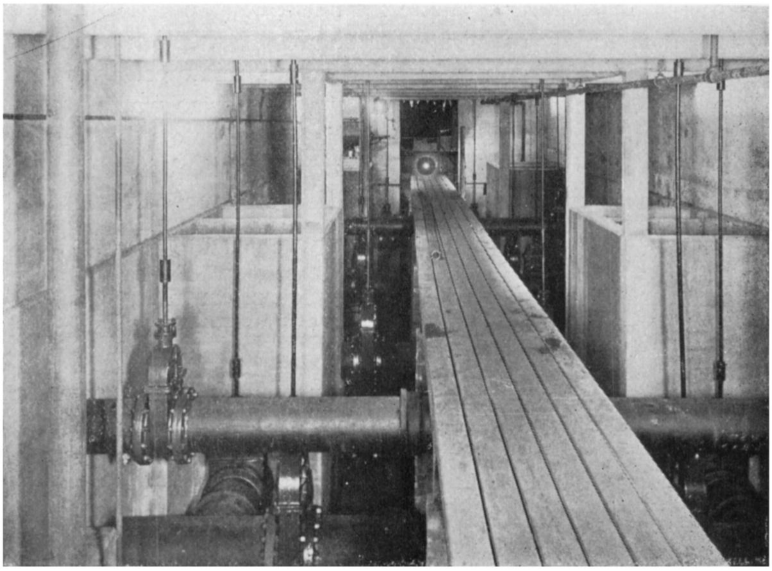


FIG. 4. PREFILTER PIPE GALLERY

FIG. 5. PREFILTER OPERATING GALLERY

controlling the prefilters. Plate III illustrates the design of the prefilters and head house and makes extended description unnecessary.

The prefilter walls are of 1:2:4 concrete, reinforced by deformed bars and designed to withstand full pressure from water level with the top of the wall and with the adjacent filter empty. The wall slabs are reinforced horizontally between vertical inside pilasters, which are reinforced vertically and tied together across the filters by reinforced concrete beams, which also serve to support the distributing piping.

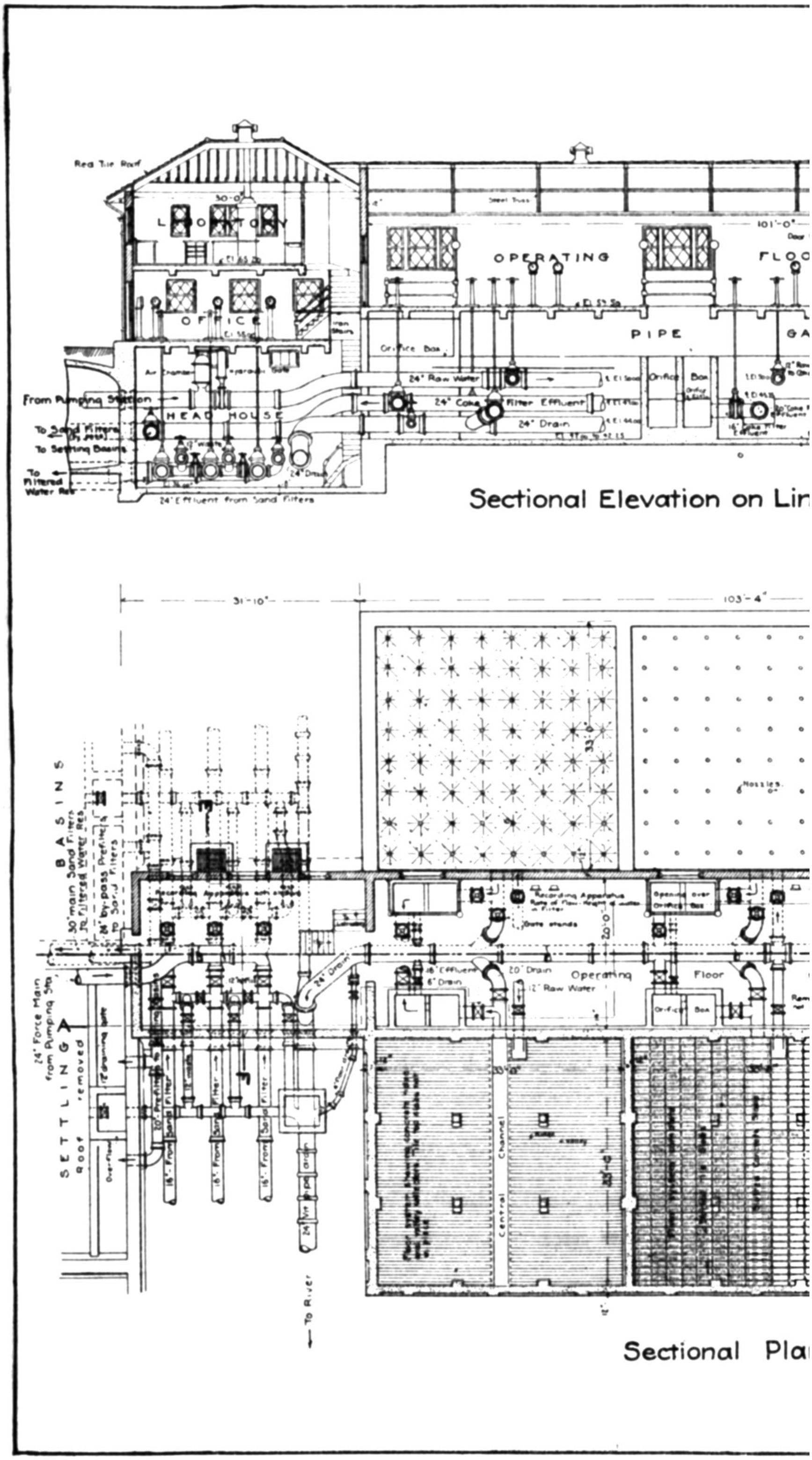
The effluent collecting system is formed of central and transverse concrete channels, covered by slotted reinforced concrete and vitrified clay slabs respectively.

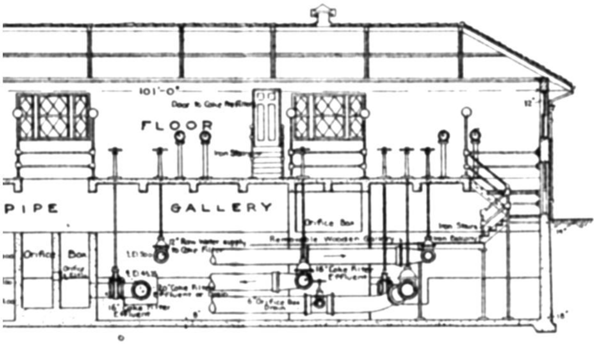
The central collecting channels connect with 20-inch pipes leading to the main drain or by branches to the orifice boxes located in the pipe gallery. In a transverse wall in these boxes there is set a brass plate with an 8-inch circular orifice, and from the difference in elevation between the surface of the water on the two sides of this orifice the rate of operating the prefilters is determined, and indicated by Simplex apparatus located in the operating gallery. The rate is controlled by the valve on the inlet raw water pipe and the depth to which the filter is backflooded by the valve in the effluent branch to the orifice boxes, the elevation of the measuring orifice being such that the filter can be operated to the entire depth as a trickler, if necessary.

To remove the accumulated deposit from the prefilter coke, the water level is raised to within 1 foot of the top of the wall, the inlet and orifice box branch valves are closed, and the drain connection opened, thus providing an outlet to the river through the 24-inch main drain. In the same trench with this drain a sanitary sewer of cast-iron was laid to prevent contamination of the well field.

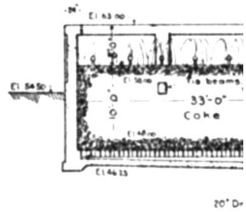
The prefiltering material is gas-house coke obtained from the local company, 1 to 3 inches in size of particle and 10 feet deep. The bottom foot was constructed of the larger coke, but above this no separation into sizes was attempted.

The prefilter effluent flows from the orifice boxes through the substructure of the head house to the settling basins, of which there are two, each of 250,000 gallons capacity. Either or both of these basins can be cut out and the prefilter effluent discharged directly to the sand filters or into the filtered water reservoir. The inlet and outlet ends are baffled by transverse walls, and the floor slopes

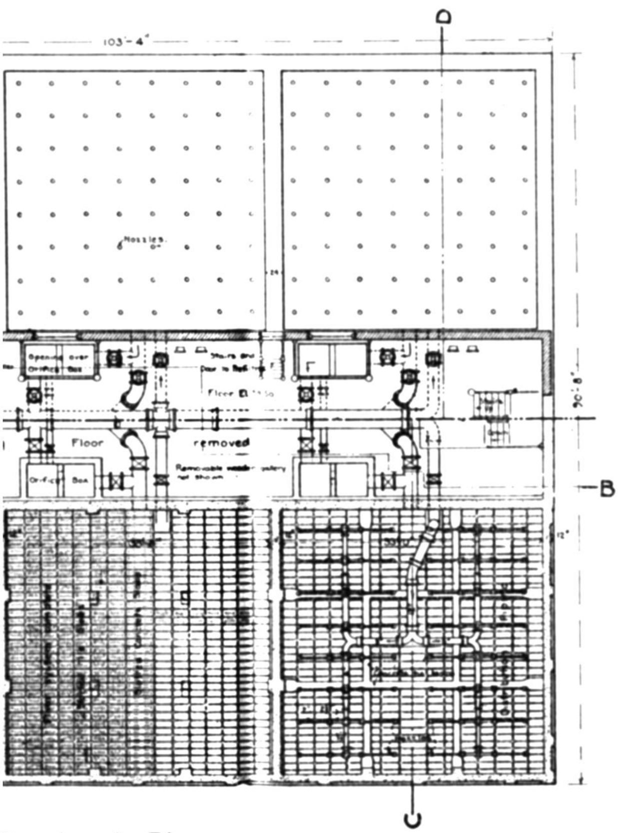

Red Tile Roof
LABORATORY
OFFICE
HEAD HOUSE
OPERATING FLOO
PIPE
From Pumping Station
To Sand Filters
To Settling Basins
To Filtered Water Res.
24" Raw Water
24" Coke Filter Effluent
24" Drain
24" Effluent from Sand Filters
Sectional Elevation on Lin
31'-10"
103'-4"
SETTLING BASINS
30" main Sand Filters to Filtered Water Res.
24" by-pass Prefilters to Sand Filters
24" Force Main from Pumping Sta.
Roof removed
Operating Floor
20" Drain
12" Raw Water
Orifice Box
Recording Apparatus
Nozzles
Central Channel
To River
Sectional Pla



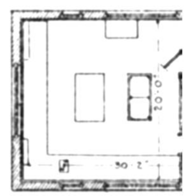
evation on Line A-B



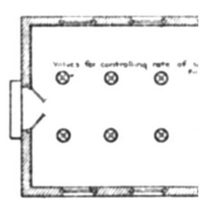
Sec



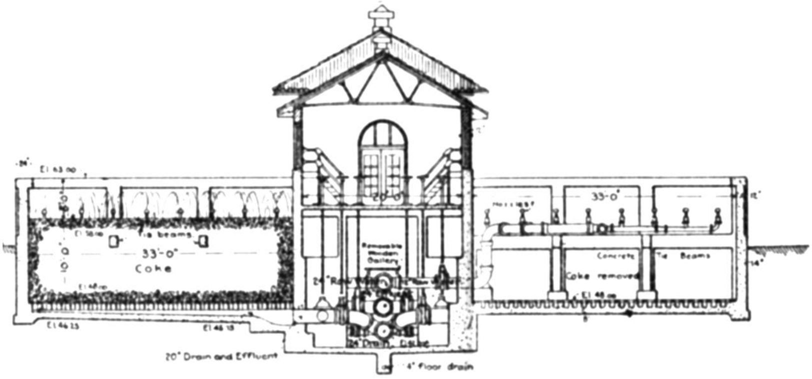
Sectional Plan



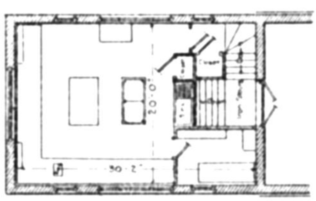
Plan of Labo



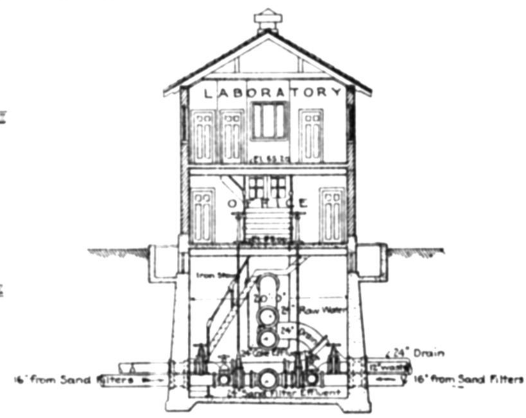
Plan of O



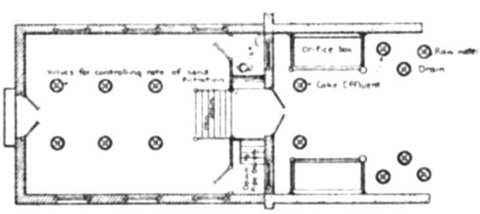
Sectional Elevation on Line C-D



Plan of Laboratory



Sectional Elevation on Line E-F



Plan of Office

LOWELL WATER WORKS

BOULEVARD PURIFICATION PLANT

Plan and Sections of

PREFILTERS, OPERATING GALLERY AND HEAD HOUSE

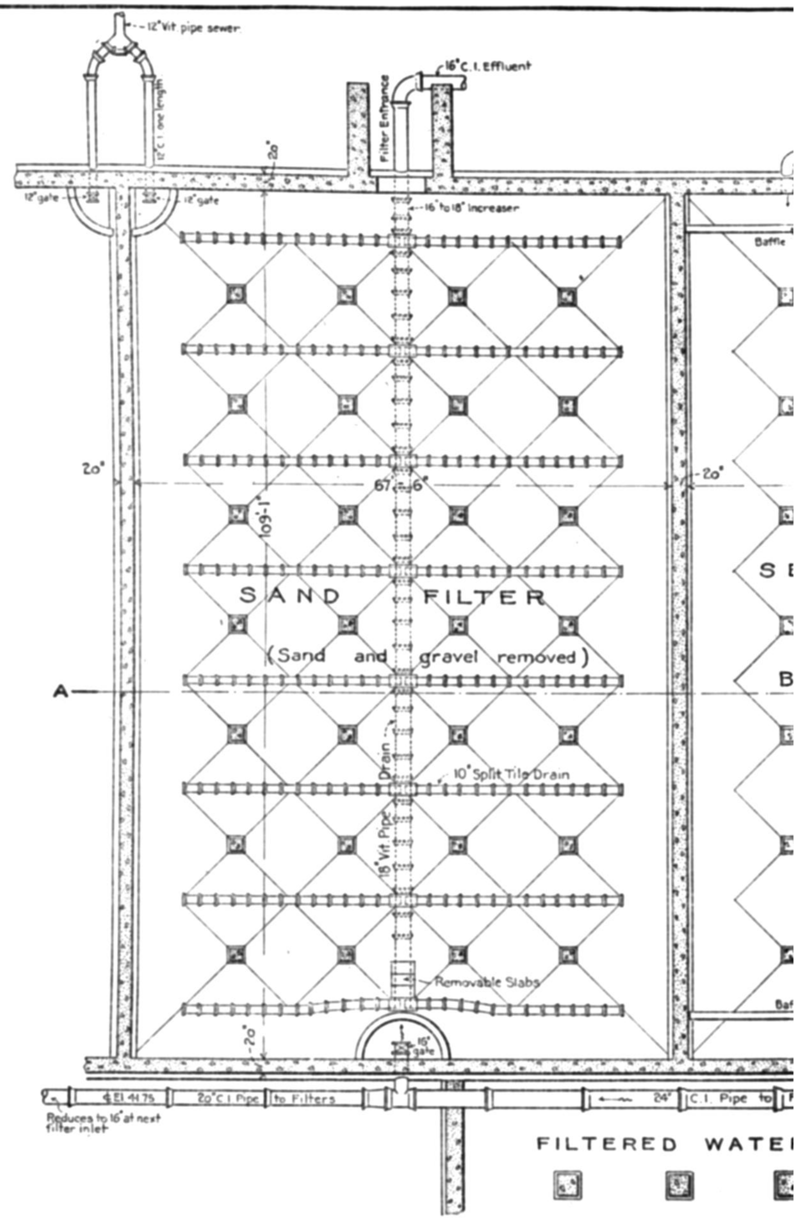
Scale

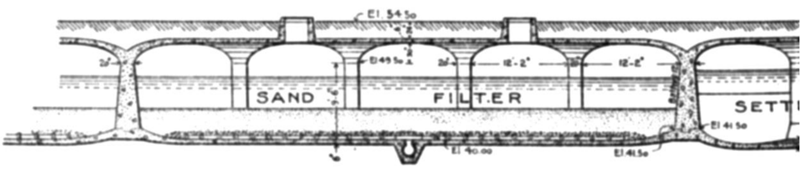
0 10 20 30 40 50

James H. Carmichael, Commissioner
Robert J. Thomas, Superintendent

F. A. Barbour,
Engineer

July 1914





Section on Line A-B
Scale 1 inch = 8 feet.

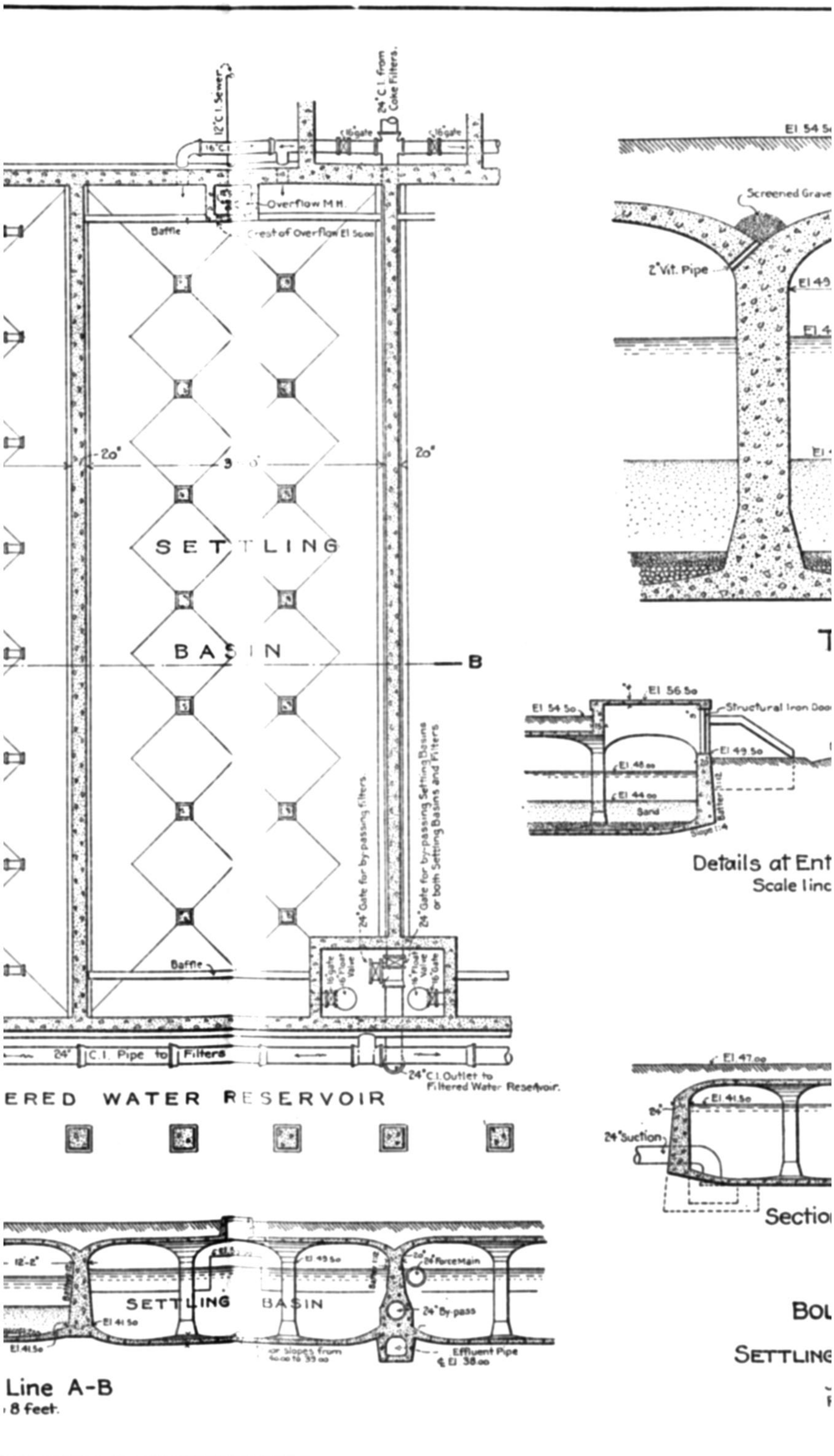
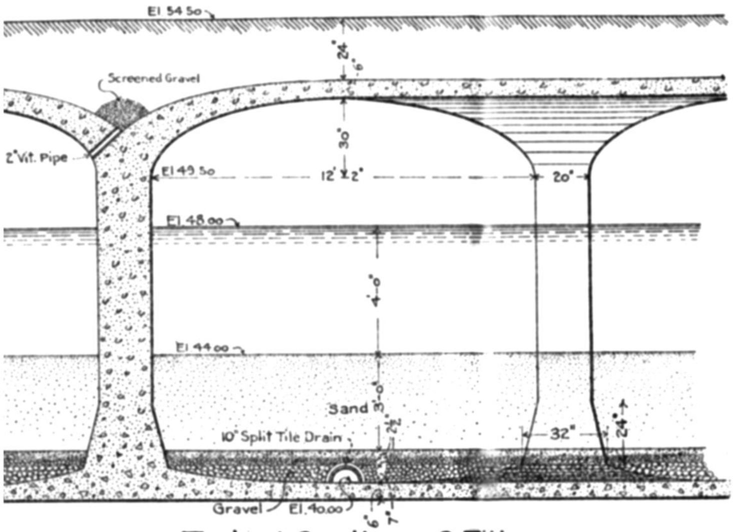
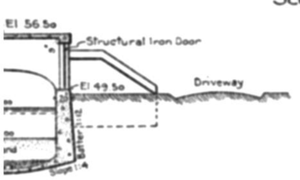

12" C.I. Sewer
24" C.I. from Coke Filters
16" gate
Overflow M.H.
Baffle
Crest of Overflow El 50.00
20"
SETTLING
BASIN
B
24" Gate for by-passing filters
24" Gate for by-passing Settling Basins or both Settling Basins and Filters
24" C.I. Pipe to Filters
24" C.I. Outlet to Filtered Water Reservoir
ERED WATER RESERVOIR
12'-2"
El 49.50
24" Force Main
24" By-pass
El 41.50
Effluent Pipe
SETTLING BASIN
Line A-B
8 feet.
El 54.50
Screened Gravel
2" Vit. Pipe
El 56.50
Structural Iron Door
El 49.50
El 48.00
El 44.00
Sand
Details at Ent
Scale 1 inc
El 47.00
El 41.50
24" Suction
Section
Bou
Settling

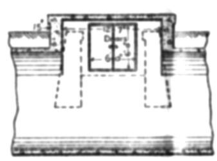
Plate IV



Typical Section of Filter

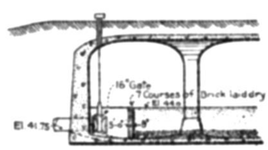
Scale 1 inch = 2 feet.





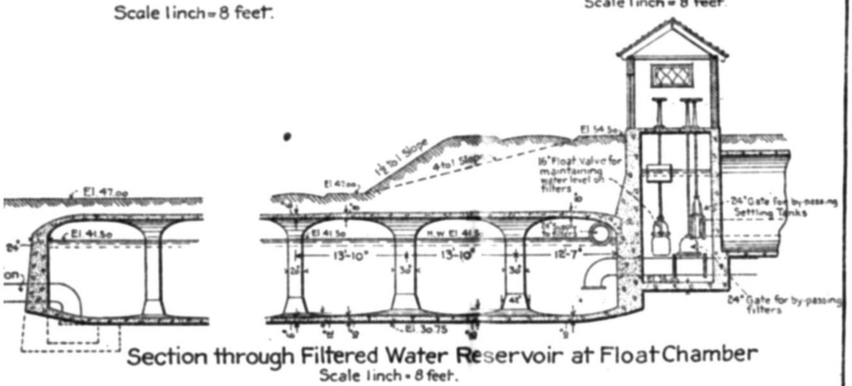
Details at Entrance to Filter

Scale 1 inch = 8 feet.



Detail of Filter Inlet.

Scale 1 inch = 8 feet.



Section through Filtered Water Reservoir at Float Chamber

Scale 1 inch = 8 feet.

LOWELL WATER WORKS

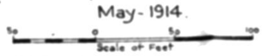
BOULEVARD PURIFICATION PLANT

Plan showing details of

SETTLING BASIN, SAND FILTERS & FILTERED WATER RESERVOIR

James H. Carmichael, Commissioner. F. A. Barbour
Robert J. Thomas, Superintendent. Engineer

May - 1914



to the inlet end where a connection with the main drain to the river permits discharge of the accumulated deposit.

The settling basins, filters (Plate IV), and filtered water reservoir are of the typical groined roof and floor construction, and demand no special consideration.

The sand filters are six in number, with a total area of 1 acre. From the gate chamber at the outlet end of the settling basins, the water is carried along the south side of the filters with branches to each unit, Plate IV. The filtering material consists of 3 feet of

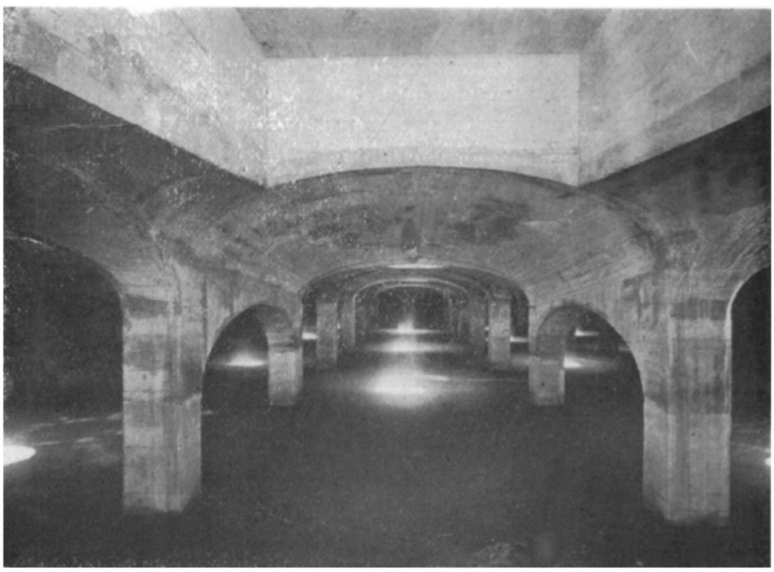


FIG. 6. SAND FILTER BED EXPOSED FOR CLEANING

sand, having an effective size of 0.35 mm. and a uniformity coefficient 1.60, supported by graded gravel in three layers, the top layer $2\frac{1}{2}$ inches thick, of material passing a $\frac{1}{8}$-inch and held by a $\frac{1}{2}$-inch screen; the middle layer $2\frac{1}{2}$ inches thick, screened between 1-inch and $\frac{3}{8}$-inch, and the bottom layer, which levels up the inverted arch floor, of material passing a 2-inch and held by a 1-inch screen.

The sand cost \$1.84 per cubic yard, delivered on top of the filter roof; the gravel was obtained from a bank at South Wilmington, screened, washed and shipped by railroad to Lowell, the cost f.o.b. cars Lowell being \$0.66 per ton for the largest size, \$1 for the in-

termediate size and $2 for the smallest size. The sand was furnished by a local contractor from a bank $1\frac{1}{2}$ miles from the plant, but on the opposite side of the river. To avoid a haul of some 6 miles by way of the nearest bridge, the material was ingeniously ferried across on a scow, which carried two two-horse carts. A light slack cable, stretched across the river at about water level, served as a guide for grooved wheels, attached to the scow, and the necessary motive power was furnished by two men pulling with about the same motion as in rowing, on a wooden lever with a transverse slot at one end which fitted on the cable with sufficient clearance to permit the lever to be easily slid directly forward along the cable, but which gripped when the pull was applied at the end of the lever.

The effluent of each sand filter unit is carried in a separate pipe to the substructure of the head house, where these pipes are cross-connected so as to permit backfilling of one filter by filtered water from an adjacent unit. In each effluent line there is placed a Venturi meter, and the rate of filtration is indicated and recorded, and the loss of head indicated for each filter unit by Simplex instruments in the office floor of the head house, (Figs. 7 and 8). In this same room are located the stands of the valves controlling the rate of filtration and also instruments indicating the elevation of the water in the settling basins and filtered water reservoir. The general arrangement is such that all operations necessary to the control of the plant can be carried out within the walls of the head house and operating gallery. The upper floor of the head house contains a well-equipped laboratory.

The filtered water, after passing the rate control valves, flows to the filtered water reservoir through a 30-inch conduit formed in the central wall of the settling basins.

From the filtered water reservoir the water is pumped to the central pumping station by turbine-driven, low-lift, centrifugal pumps, installed by the Kerr Turbine Company, two units being provided, one of 7,000,000 and one 10,000,000 gallons capacity. The turbine speed is reduced by helical gears, surface condensers are set in the suction lines, the air pumps are driven by chains from the main shafts and the outboard end of each main shaft carries a small direct-current generator by which the pumping station and purification plant are lighted. A Venturi meter in the force main records the amount of water delivered to the city. Steam for heating the purification plant is piped from the pumping station

FIG. 7. PREFILTERS, OPERATING GALLERY SUPERSTRUCTURE AND HEAD HOUSE

FIG. 8. HEAD HOUSE, FIRST FLOOR

and the lighting current is transmitted through a cable laid in the same trench.

The following tabulation summarizes the results of tests of the turbo-centrifugal pumping units:

	SMALL UNIT	LARGE UNIT
Date of test	June 16, 1916	June 19, 1916
Length of run	2 hours	2 hours
Discharge rate, m.g.d	7,020,000	10,020,000
Total head, feet	20.23	45.22
Steam pressure at throttle, pounds gauge	122.20	122.00
Vacuum, inches, barometer = 29.75	28.48	29.19
Speed pump, r.p.m.	640.00	771.00
Total steam, pounds	1,696.20	3,469.50
Moisture, per cent	3.20	1.88
Dry steam, pounds	1,641.90	3,404.30
Dry steam, pounds per hour	820.95	1,702.15
Water h.p.	24.95	76.00
Dry steam, pounds per water h.p. hour	32.94	22.40

In determining water horse-power no allowance is made for the head lost through the condenser, nor for work done in driving the air pump. The generators were disconnected during the tests. The efficiencies obtained were about 12 per cent better than the contract guarantees and the apparatus has given entire saitsfaction during the past year, with the exception of the chain drive of the air pump from the main shaft. Such a drive provides the neatest and most economical arrangement for small units, where the exhaust from steam-driven air pumps cannot be utilized, but chains heavier than ordinarily required for the same load and heavy fly wheels or spring sprockets are necessary to overcome the reciprocating action of the air pump and prevent whipping and excessive stretch and wear of the chain.

A brief reference to the effect of cleaning the 9600 feet of 24-inch force main leading from the Boulevard Station to the city may be of interest. This pipe, laid in 1896, had carried for years the metal-laden well water, and the friction loss had become so great that in 1914 cleaning was recommended. Tests in May, 1914, with rates of discharge, measured by pump displacement, varying from 4,500,000 to 6,000,000 gallons per day, made by tapping three mercury columns in the pipe at distances of 2,500 and 3,600 feet apart,

showed values of C in the Hazen and Williams formula ranging from 56.5 to 58.0. The pipe when opened was found to be coated with a heavy, smooth, metallic slime, varying in thickness from $\frac{1}{4}$-inch at the top to $\frac{1}{2}$-inch or more at the bottom of the pipe, but without marked incrustation or roughness of surface. The main was cleaned in September by the National Water Main Cleaning Company and a test made immediately after the cleaning, in the same way as the earlier test, showed for rates of discharge varying from 4,500,000 to 6,000,000 gallons per day, values of C ranging from 124.0 to 127.0. Unfortunately, however, before the purification plant was completed the pipe had rapidly again become dirty and the value of C was found to approximate 85 in November, 1915. The capacity of a soft slime to greatly increase frictional resistance is the interesting condition in the foregoing experience; it is not intended to suggest that where loss of head is due to incrustation the effect of cleaning would so rapidly disappear.

CONSTRUCTION OF PURIFICATION PLANT—COSTS

The purification plant was built partly by city labor and partly by contract, an arrangement which, in a measure, met the demands of local labor leaders but materially added to the cost of the work.

All earth work, the placing of coke, sand and gravel in the filters, and the laying of vitrified clay pipe, was done by city labor; the concrete masonry substructures, filter underdrains and all cast-iron piping were included in a contract which was let to The Charles R. Gow Company of Boston, the lowest bidder.

Work was begun in September, 1914, and practically completed a year later. The contractor was experienced and the mixing and placing of the concrete and the handling of the forms were done economically by a simple but effective plant.

The sand and stone for concrete were hauled from a bank 2000 feet from the work, without screening, the stone ranging from small pebbles to large cobbles. The run of the bank was passed through a crusher, raised by a conveyor to a revolving screen discharging into elevated sand and stone bins, from which by a measuring outlet arrangement the materials were delivered to the mixers in the desired proportions. The mixers discharged into buckets which were moved on small cars running east and west and just north of the masonry structures. From these cars the buckets were

TABLE 5

Cost of Boulevard purification plant, including pumping station extension and pumps

ITEMS	PREFILTERS, EXCLUDING HEAD HOUSE	SETTLING BASINS	SAND FILTERS, HEAD HOUSE, SEWERS AND DRAINS	FILTERED WATER RESERVOIR	PIPE FROM STATION TO FILTRATION PLANT	LOW-LIFT PUMPS AND STATION CHANGES	TOTAL COST
Earth excavation	$1,935.89	$1,681.00	$11,994.68	$8,940.00	$2,058.00	$741.44	$27,351.01
Concrete masonry							
Cement, $1.80 per bbl	3,020.00	2,182.00	10,842.16	3,660.00	53.00	459.00	
Puddle, $4 per cu. yd	19.00	4.00					
Floors, $4.50 per cu. yd		1,180.00	5,570.00	2,120.00		179.00	
Walls, $5.75 per cu. yd		1,662.00	8,025.39	2,540.00	116.00	612.73	
Piers, $6.75 per cu. yd. Roofs, $6.75 per cu. yd.		1,735.00	9,360.00	3,360.00		120.00	
In prefilters	11,564.06						
In head house		312.00	1,559.00				
Total	14,603.06	7,064.00	35,356.55	11,680.00	169.00	1,470.73	70,343.34
Steel reinforcement							
Bars, 2.5¢ per lb	2,169.33	162.00	758.00	34.00	5.00	25.00	
I beams, 5¢ per lb	426.40		276.10			186.25	
Total	2,595.73	162.00	1,034.10	34.00	5.00	211.25	4,042.08
Coke in prefilters							
Material, $4.75 per ton	4,716.99						
Placing	505.04						
Total	5,222.03						5,222.03
Gravel in sand filters							
Material			4,001.05				
Placing (1200 cu. yds.)			919.41				
Total			4,920.46				4,920.46
Sand in sand filters							
Material			9,439.20				
Placing (5130 cu. yds.)			916.66				
Total			10,355.86				10,355.86
Underdrains, sand filters			960.00				960.00
Prefilters							
Distributors	3,411.27						
Floor slabs	567.60						
Total	3,978.87						3,978.87
Cast iron pipe, etc.							
Pipe, $21.95 per ton	527.00	611.00	4,181.40		3,725.42		
Specials, $69.90 per ton	2,710.00						
Valves	2,006.85	445.00	1,227.63		236.00		
M. H. frames, covers, etc		187.00	1,143.70	88.00			
Placing and mis	906.15	146.00	1,496.93		1,262.26		
Total	6,150.00	1,389.00	8,049.66	88.00	5,223.68		20,900.34

Sewers, drains, etc	1,426.72		1,426.72				2,853.44
Recording apparatus	970.41	128.41	2,031.04	34.10		876.69	4,040.65
Pumping machinery						12,182.28	12,182.28
Buildings, etc.							
Structures	8,617.33	1,050.00	4,950.00			2,097.52	
Heating	684.47		394.00				
Lighting	85.00		59.00			586.57	
Laboratory, mis			1,267.10				
Total	9,386.80	1,050.00	6,670.10			2,684.09	19,790.99
Total construction	46,269.51	11,474.41	82,799.17	20,776.10	7,455.68	18,166.48	186,941.35
Administration and mis	562.00	137.00	980.58	247.00	89.00	217.00	2,233.42
Engineering and inspection	2,760.00	685.00	4,917.25	1,245.00	452.00	1,085.00	11,144.25
Total cost	49,591.51	12,296.41	88,697.00	22,268.10	7,996.68	19,468.48	200,319.02
Per million gallons daily capacity	4,959.00	1,230.00	8,870.00	2,227.00	800.00	1,947.00	20,032.00

picked up and dumped by the boom of a stiff-legged derrick, which was supported on the roof of the filters and settling basins and was moved easterly on the central line of these structures as the work progressed.

When water was turned into the plant it was found by test that while the settling basins and filtered water reservoir practically met the contract requirements of a leakage not to exceed $\frac{1}{4}$ inch in depth per twenty-four hours, the sand filters were losing approximately 500,000 gallons daily. As the only structural condition in which the sand filters differed from the settling basins and filtered water reservoir was the main underdrain collector of 18-inch vitrified pipe, surrounded by 6 inches of concrete and laid below the floor of the filter, these drains were first suspected and afterwards proved by test to be the location of the trouble. The filtering material had been placed before opportunity occurred to test the masonry structures for tightness, but by removing the sand and gravel overlying the inspection manholes at either end of the drain, access thereto was possible. Examination showed the pipe to be in good alignment and unbroken, but the joints to be imperfectly filled with cement. The fact that these drains were to be surrounded by concrete had apparently led to lax workmanship and inspection of the joint filling. The contractor, in order to avoid the expense of removing the sand, gravel and filter floor, undertook to stop the leakage by filling the joints in the inside with quick-setting cement, washing with grout, and after drying, painting with asphalt, a long, tedious job, as laborers competent and willing to work in an 18-inch pipe are not plentiful. In this way the leakage, while not altogether stopped, was so far reduced that at the time of the last test the total loss from the six filter units was somewhat less than 50,000 gallons per day, on which basis the work was accepted. The lesson is the necessity of the most careful inspection and testing for tightness of main underdrain collectors before the filter floor is laid.

Table 5 shows the total cost of the purification plant, including day labor and contract work, and also the distribution of the cost, so far as possible, to the different parts of the plant and to the various classes of work. The pay of city laborers ranged from \$2 to \$2.50 per eight-hour day, with an approximate average of \$2.15 per day.

The appended statement of actual cost of the work to the contractor, graciously furnished by Charles R. Gow from accurate material and labor accounts will, it is believed, prove of general value.

OPERATION OF THE PURIFICATION PLANT

Water was first applied to the prefilters in October, 1915, but it was not until July, 1916, that the sand filters were placed in regular service. This was because of the time required to ripen the prefilters, the desire to avoid starting the sand filters in winter without more knowledge of what surface cleaning would involve, and finally because of the delay caused by the necessary repairs to the underdrain system.

TABLE 6

Monthly averages of analyses of water as drawn from wells in 1916

MONTH	DISSOLVED OXYGEN. PERCENT OF SATURATION	PARTS PER MILLION		
		Carbonic acid	Iron	Manganese
January	11.6	22.8	1.64	2.53
February	11.4	21.8	2.20	2.44
March	11.2	22.0	2.34	2.56
April	12.8	22.0	1.64	2.45
May	15.6	21.4	2.28	1.94
June	14.9	20.8	2.35	1.73
July	14.2	20.8	1.92	1.59
August	15.0	21.3	2.28	1.69
September	16.0	21.4	2.49	1.89
October	15.8	21.1	2.51	1.89
November	15.3	21.0	2.28	2.05
December	16.7	20.2	2.09	2.09
Average	14.0	21.4	2.16	2.07

Table 6 shows monthly averages of analyses of the ground water as drawn from the wells during the year 1916. The free ammonia in the well water averaged for the year 0.33 p.p.m., the albuminoid ammonia 0.057 p.p.m. and the total hardness 25 p.p.m.

The prefilters have been operated at an average rate of approximately 50,000,000 gallons per acre daily. The carbonic acid and dissolved oxygen in the water, as applied to the prefilters after aeration, have averaged 14.0 p.p.m. and 52.9 per cent of saturation respectively. The prefilters have been back-flooded to an elevation 1 to 2 feet below the surface of the coke, and the carbonic acid and dissolved oxygen in the effluent have averaged 13.3 parts per million and 54.5 per cent of saturation.

Tables 7 and 8 show the work done by the prefilters and settling basins in the removal of iron and manganese, during 1916.

TABLE 7

Monthly averages of iron in prefilter effluent and settling basin effluent

DATE	IRON—P.P.M.		IRON—PERCENTAGE REMOVED	
	Prefilter effluent	Settling basin effluent	By Prefilters	By prefilters and settling basins
January	0.95	0.89	42.0	45.8
February	0.95	0.84	56.8	61.8
March	0.95	0.75	59.4	68.0
April	0.79	0.58	51.7	64.6
May	0.90	0.57	60.6	75.0
June	1.06	0.58	54.8	75.3
July	0.89	0.76	53.7	60.4
August	1.14	0.84	50.0	63.2
September	1.29	0.98	48.2	60.6
October	1.34	1.00	51.4	60.2
November	1.16	0.88	49.1	61.4
December	1.05	0.86	49.8	58.8
Average	1.04	0.79	52.0	63.4

TABLE 8

Monthly averages of manganese in prefilter effluent and settling basin effluent

DATE	MANGANESE—P.P.M.		MANGANESE—PERCENTAGE REMOVED	
	Prefilter effluent	Settling basin effluent	By prefilters	By prefilters and settling basins
January	1.93	1.85	23.7	26.9
February	1.78	1.70	27.1	30.3
March	1.70	1.62	33.6	36.8
April	1.64	1.57	33.1	35.9
May	1.23	1.15	36.6	40.8
June	1.05	1.00	39.3	42.2
July	0.93	0.82	41.5	48.4
August	0.97	0.88	42.6	47.9
September	0.96	0.92	49.2	54.4
October	1.14	1.08	39.7	42.9
November	1.05	0.95	48.7	53.7
December	1.08	0.96	48.3	54.1
Average	1.29	1.21	37.8	41.6

The removal of 52.0 per cent of the iron and 37.8 per cent of the manganese, or the interception of about 100 pounds of metal daily by the prefilters, makes the unloading of the resulting mass of hydrate an important factor in the control of the plant. This is accomplished by filling the prefilter tank to within 1 foot of the top of the wall and then opening the gate in drain to river. The 4 feet of water over the coke, under average conditions, disappears in 5 minutes or falls 10 inches per minute, providing a velocity through the voids in the coke sufficient to remove all but a fairly constant percentage of the metallic deposit. On the average the prefilters have been flushed once a week during the past year, and the wash water used has equaled 0.80 per cent of the quantity filtered. In addition to the weekly flushing, the upper 8 to 12 inches of the coke has been loosened by forks at intervals of about one month to prevent matting. Experience to date indicates that by this weekly flushing and occasional loosening of the surface layer the deposit of metallic hydrates in the coke can be controlled, and a uniform condition maintained.

The settling basins were cleaned once during 1916, a deposit of about one inch of gelatinous iron and manganese precipitate being flushed into the sewer. From Tables 7 and 8 it will be seen that the settling basins removed only 11 and 4 per cent respectively of the iron and manganese in the raw water. The provision of one or more contact baffles of coarse gravel in each of these basins to assist coagulation and intercept some of the metallic hydrate which now reaches the sand filters has been suggested by the author.

The sand filters have been in continuous service since July, 1916, and have operated at rates varying from 6,000,000 to 7,000,000 gallons per acre daily, depending on the water used by the city. During the year a small experimental sand filter, receiving effluent from prefilter 3, has been run with equally good results at a rate of 10,000,000 gallons per acre daily, and there is no doubt that when the demand makes necessary, a rate of 10,000,000 gallons per acre daily or higher can be maintained in the sand filters.

Table 9 shows monthly averages of iron and manganese in the sand filter effluent from August, 1916, to February, 1917, inclusive.

During the seven months to March, 1917, in which the sand filters have been in regular operation, the iron in the raw water has been reduced from 2.12 p.p.m. to 0.27 p.p.m. and the manganese from 2.14 p.p.m. to 0.03 p.p.m. The water as it leaves the

TABLE 9

Iron and manganese in sand filter effluent

DATE	IRON	MANGANESE
	parts per million	*parts per million*
August, 1916	0.30	0.11
September	0.31	0.01
October	0.29	0.02
November	0.26	0.00
December	0.24	0.02
January, 1917	0.25	0.05
February	0.23	0.03
Average	0.27	0.03

plant is clear and colorless, and experiments indicate that no subsequent precipitate of the residual metallic contents occurs in the water, either cold or hot.

The sand filters, thus far, have been raked when the loss of head, due to the accumulation of surface deposit, reaches 5.0 feet or two-thirds of the maximum possible loss of head. The yield between rakings has ranged from 100,000,000 to 50,000,000 gallons per acre, growing less with each raking and finally necessitating scraping and removal of the surface slime. To March 1, the filters had been scraped twice, about 1 inch of sand being removed each time. The yields between scrapings were 467,000,000 and 412,000,000 gallons per acre, the decreased yield of the second run being due to compacting of the sand by inexperienced workmen rather than of general significance.

The cost of raking has averaged $0.20 per million gallons filtered, of scraping and removing the dirty sand $0.50 per million gallons filtered, or a total of $0.70 per million gallons filtered. No sand has as yet been washed or replaced. These costs are unnecessarily high, due to the inexperience of the workmen and to the fact that adequate pressure for the operation of the ejector is not yet available.

To H. H. Chase, M.Am.Soc.C.E., of the author's office, credit is due for work on the design and general supervision of construction. C. L. Rice was resident engineer during construction and is now chemist in charge of the plant, and to him acknowledgment is also due for valuable assistance rendered.

Lowell Purification Plant, 1914–1915:—Cost of Work to Contractor

Compiled by Charles R. Gow, Contractor

Note.—Laborers	$0.25 per hr.	Superintendent	$6.00 per day
Carpenters	0.50 per hr.	Sub-foremen	4.00 per day
Hoisting engineers	0.50 per hr.	Team and driver	5.00 per day

No charge made for personal services of contractor.

General expense items—Superintendent and miscellaneous

(Chargeable to all classes of work in contract)

General labor (including insurance)	$3,830.01
General supplies	1,150.90
Plant depreciation	1,000.00
	$5,980.91 = 8.8 per cent of contract

Cement—11,306.2 barrels

Cement and miscellaneous supplies	$1.281 per barrel		
Labor handling	.053 per barrel		
Teaming	.117 per barrel		
Cost per barrel on work		$1.451	
Cement Shed			
Labor building	$ .007 per barrel		
Materials	.02 per barrel		
Cost per barrel		.027	
Superintendent and miscellaneous, 8.8 per cent on all costs per barrel (see above)		.129	
Total cost of cement per barrel			$1.607

Reinforcing steel—127,245 pounds

Steel (deformed bars)	$ .0157 per pound		
Labor bending and placing	.0040 per pound		
Teaming to job	.0104 per pound		
Total cost of steel in place		.0301	
Superintendent and miscellaneous, 8.8 per cent on all costs		.0027	
Total cost of this item per pound			.0328

Structural steel—17,776 pounds

Steel	$ .0314 per pound	
Labor handling and placing	.0065 per pound	
Teaming to job	.0011 per pound	
Total cost of structural steel per pound		.0390

Superintendent and miscellaneous, 8.8 per cent on all costs		$ .0034	
Total cost of this item per pound			$0.424

Concrete

General charges—7,828.9 cubic yards total.

(Chargeable to all classes of concrete)

Installing and removing plant

General transportation of plant			
Labor loading	$ .0234 per cubic yard		
Labor unloading	.0157 per cubic yard		
Freight	.0166 per cubic yard		
Teaming	.0772 per cubic yard		
Total for this division per cubic yard		$ .1329	
Erecting, repairing and removing concrete and crusher plant			
Labor	$ .2613 per cubic yard		
Material	.1858 per cubic yard		
Total for this division per cubic yard		.4471	
Erecting and removing derricks			
Labor	$ .0779		
Materials and superintendent	.0679		
Total for this division		.1458	

Furnishing sand, gravel and crushed stone

Loading and hauling			
Labor loading	$ .3310		
Teaming to crusher pit	.5245		
Total for this division		.8555	
Operating crusher and screening plant			
Labor	$ .2262		
Miscellaneous supplies	.0572		
Coal and oil	.2515		
Teaming coal	.0402		
Total for this division		.5751	
Total cost of general charge			$2.1564

General forms—7,828.9 cubic yards

(Chargeable to all form work)

Carpenter shop		
Labor	$ .0225 per cubic yard	
Materials	.0353 per cubic yard	
Miscellaneous supplies	.0298 per cubic yard	
Total cost this item per cubic yard		$ .0876

Concrete in filter floors—2,017.6 cubic yards

Not including cement

Forms				
Building				
Labor	$ .0265 per cubic yard			
Materials	.0298 per cubic yard			
Total cost of this division		$ .0563		
Labor erecting		.2489		
General forms (as above)		.0876		
Total cost of forms per cubic yard			$ .3928	
Concrete				
Labor mixing		$ .4594		
Labor placing		.8874		
Supplies		.0064		
General concrete (as above)		2.1564		
Total cost of this division per cubic yard			3.5096	
Superintendent and miscellaneous, 8.8 per cent on all costs			.3434	
Total cost this item per cubic yard				4.25

Concrete in filter walls—2,254.7 cubic yards

Not including cement

Forms		
Building		
Labor	$ .0385 per cubic yard	
Materials	.3407 per cubic yard	
Total cost of this division		$ .3792
Erecting labor	$ 1.4041	
General forms	.0876	
Total cost of forms per cubic yard		$1.8709

Concrete			
Labor mixing	$ .4349		
Labor placing	.6653		
Supplies	.0250		
General concrete	2.1564		
Total cost of this division		$3.2816	
Manholes			
Labor	$ .0453		
Materials	.0110		
Total cost of this division		.0563	
Superintendent and miscellaneous, 8.8 per cent on all costs		.4584	
Total cost this item per cubic yard			$5.67

Concrete in piers—276.8 cubic yards

Not including cement

Forms			
Building			
Labor....... $ .4620 per cubic yard			
Materials... 1.2234 per cubic yard			
Total cost of this division	$1.6854		
Labor erecting	2.32		
General forms	.0876		
Total cost of forms per cubic yard		$4.0930	
Concrete			
Labor mixing	$ .5560		
Labor placing	1.1220		
General concrete	2.1564		
Brick	.2240		
Total cost of this division per cubic yard		4.0584	
Superintendent and miscellaneous, 8.8 per cent on all costs		.7173	
Total cost this item per cubic yard			$8.87

Concrete in groined arch roof—1,883.2 cubic yards

Not including cement

Forms	
Building	
Labor....... $ .307 per cubic yard	
Materials... .4359 per cubic yard	
Total cost of this division	$.7429

Labor erecting	$1.4062		
General forms	.0876		
Total cost of forms per cubic yard		$2.2367	
Concrete			
Labor mixing	.3322		
Labor placing	.9230		
General concrete	2.1564		
Supplies	.0372		
Total cost of this division per cubic yard		3.4488	
Superintendent and miscellaneous, 8.8 per cent on all costs		.5003	
Total cost of this item per cubic yard			$6.19

Prefilter concrete—1,396.6 cubic yards

Not including cement

Forms			
Labor erecting	$2.1326 per cubic yard		
Materials	.9780 per cubic yard		
General forms	.0876 per cubic yard		
Total cost of forms per cubic yard		$3.1982	
Concrete			
Labor mixing	$ .3114		
Labor placing	1.4514		
General concrete	2.1564		
Total cost of this division per cubic yard		3.9192	
Special plant			
Tower labor Erecting	$ .2425		
Tower materials	.0663		
Rental of hoist engine	.1790		
Total cost of this division per cubic yard		.4878	
Tile slabs			
Material	$ .3297		
Labor placing	.09		
Teaming	.0257		
Total cost of this division per cubic yard		.4454	
Waterproofing—Saum's preservative		.1575	
Superintendent and miscellaneous, 8.8 per cent on all costs		.7223	
Total cost this item per cubic yard			$8.93

Underdrains in six sand filters—3,192 linear feet

	Per linear foot	Per filter
Pipe	$ .2023	$107.63
Labor and teams	.0924	49.17
Total cost of pipe and labor	$ .2947	$156.80
Superintendent and miscellaneous, 8.8 per cent on all costs	.0293	13.80
Total cost of this item	$ .3240	$170.60

Cast iron pipe—338.6 tons

Labor laying and caulking		$5.305 per ton		
Teaming		.437 per ton		
Erecting trolley				
Labor	$ .071			
Materials	.082	.153		
Total for this division per ton			$5.895	
Superintendent and miscellaneous, 8.8 per cent on all costs			.519	
Total cost this item per ton				$6.41